

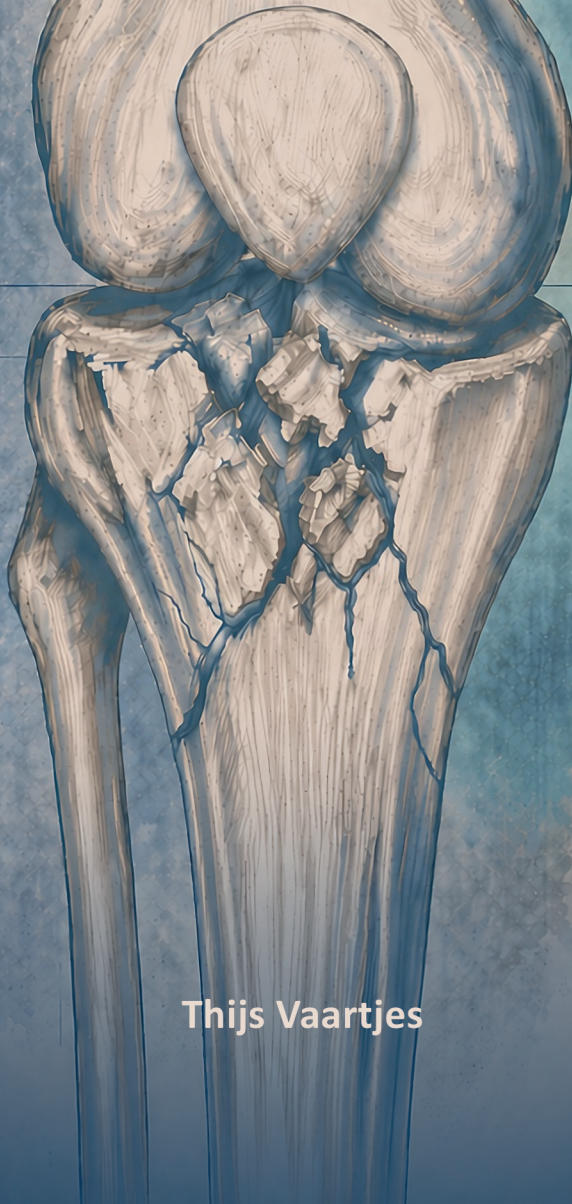
Functional Outcomes after Tibial Plateau Fractures

From Injury to Treatment and Recovery

TIBIAL PLATEAU
FRACTURE

ANTERIOR VIEW

Thijs Vaartjes



Functional Outcomes after Tibial Plateau Fractures

From Injury to Treatment and Recovery

Thijs Vaartjes

COLOFON

Financial support for the printing of this doctoral thesis has been provided by:

University of Groningen, University Medical Center Groningen, Graduate School of Medical Sciences, Nederlandse Vereniging voor Traumachirurgie, Traumaplatform, Noord Negentig, Chipsoft, Sectra, Oudshoorn and Pasquil.



ISBN: 978-94-6537-587-8

Cover design and lay-out: Arina van Londen | www.ridderprint.nl

Printing: Ridderprint | www.ridderprint.nl

Copyright © 2026 by T.P. Vaartjes

All rights reserved. No part of this thesis may be reproduced or transmitted in any form or by any means, without prior permission from the author.



rijksuniversiteit
 groningen

Functional Outcomes after Tibial Plateau Fractures

From Injury to Treatment and Recovery

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. ir. J.M.A. Scherpen
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

woensdag 17 juni 2026 om 16.15 uur

door

Thijs Pieter Vaartjes

geboren op 21 april 1995

Promotores

Dr. F.F.A. IJpma

Prof. dr. J.N. Doornberg

Copromotor

Dr. N. Assink

Beoordelingscommissie

Prof. dr. M.H.J. Verhofstad

Prof. dr. T.C. Kwee

Prof. dr. C.K. van der Sluis

TABLE OF CONTENTS

Chapter 1	General introduction	9
PART I	How do they occur	21
Chapter 2	What is the patient-reported outcome, complication rate and conversion to total knee arthroplasty in patients with tibial plateau fractures caused by high-energy compared to low-energy mechanisms of injury?	23
Chapter 3	Tibial plateau fracture morphology based on injury force mechanism is predictive for patient-reported outcome and conversion to total knee arthroplasty	41
PART II	How are they treated	57
Chapter 4	Functional Outcome After Nonoperative Management of Tibial Plateau Fractures in Skeletally Mature Patients: What Sizes of Gaps and Stepoffs Can be Accepted?	59
Chapter 5	What Is the Patient-reported Outcome and Complication Incidence After Operative Versus Nonoperative Treatment of Minimally Displaced Tibial Plateau Fractures?	77
Chapter 6	What Is the Association Between Radiographic Measurements of Initial and Residual Fracture Displacement, Tibial Alignment, and Recovery in Terms of Patient-reported Outcome After Surgical Treatment of Tibial Plateau Fractures?	97
PART III	How do they recover	121
Chapter 7	Most patients with tibial plateau fractures regain function for daily activities but do not return to their pre-injury level of sport: comparison of multicenter cohort of 1101 patients and age-related peers	123
Chapter 8	What is the course of recovery regarding symptoms, pain, daily activities, sports and quality of life after tibial plateau fractures within the first year after injury: a prospective multicenter study including 280 patients	153
Chapter 9	General discussion	173

Appendices	Summary	184
	Samenvatting	188
	Dankwoord	193
	List of publications	196
	About the Author	198

Chapter 1



General introduction

TIBIAL PLATEAU FRACTURES

The tibial plateau is part of the knee, which is essential for daily activities like walking, working, or playing sports. During these daily activities, the knee endures weights varying from 2.6 times the bodyweight when walking on a flat surface to 3.5 times the bodyweight when walking downstairs [1]. The tibial plateau forms the lower part of the knee's weight-bearing articular surface and consists of a lateral and medial plateau, separated by an intercondylar eminence. The lateral and medial plateau are different in terms of architecture and bone density, with the medial side bearing approximately 60% of the body weight. The medial part of the tibial plateau is therefore more sclerotic and stronger than the lateral side and less likely to fracture during an accident [2,3]. The balance and stability of the knee joint is formed by soft tissue structures which are frequently involved in tibial plateau fractures [4,5]. Some of these structures include the lateral and medial collateral ligaments, which provide varus, valgus and rotational stability, the anterior and posterior cruciate ligaments, which resist rotational loads and anterior or posterior tibial translation, and the menisci, which provide stability, shock absorption, and increase the congruity between the femur condyles and tibial plateau [6–10]. Fractures of the tibial plateau are relatively rare, accounting for only 1-2% of all fractures and approximately 8% of fractures in the elderly patient population [2,11]. In male patients, these fractures mostly occur before the age of 50 years, whereas in female patients, they mostly occur after the age of 50 years [12]. The general reported incidence is around 25-27 per 100.000 and increased from 21 per 100.000 in 2006 to 29 per 100.000 in 2018. This results in more than 5000 patients requiring treatment annually in the Netherlands only [12–14]. Due to the growing elderly population within the western societies, one out of every six persons will be 60 years or older by 2030 [15]. Therefore, the number of patients with a tibial plateau fracture is expected to increase continuously, which will have a major impact on the Dutch healthcare system.

HOW DO THEY OCCUR

Tibial plateau fractures are caused by varus (inward) or valgus (outward) force, combined with axial load and flexion, extension or hyper extension of the leg during high- or low-energy trauma mechanisms [16,17]. High-energy traumas are mostly caused due to high velocity motorized vehicle accidents or falls from height, and are more frequently seen in younger, especially male, patients. The high impact during these trauma mechanisms usually results in more complex multi-fragmentary fracture patterns involving both the lateral and medial tibial plateau [3,12,18]. Low-energy traumas are mostly caused due to bicycle accidents, walking, indoor activities or a fall from standing height, and are more often seen in elderly, especially female, patients [12,19,20]. The lower impact during

these trauma mechanisms usually results in relatively more simple fractures involving only the lateral tibial plateau. Although, in the elderly patients, complex multi-fragmentary fracture patterns are also seen after low-energy trauma due to age-related changes in bone structure caused by osteoporosis [2,12,21,22]. The amount of energy involved in traumas causing tibial plateau fractures can also lead to significant damage of the surrounding soft tissues (e.g. ligaments and menisci), which may impact functional outcome, especially after high-energy trauma [3]. Recently Xie et al. described six different injury force mechanisms: valgus-flexion, valgus-extension, valgus-hyperextension, varus-flexion, varus-extension and varus-hyperextension, creating unique tibial plateau fracture patterns. Their study demonstrated that these different mechanisms are associated with different soft tissue injuries, suggesting a potential impact on functional recovery [16]. However, study findings regarding outcome after these different trauma mechanisms are inconclusive. While some report good and some report worse outcomes after high-energy trauma, others do not even consider trauma mechanism as a factor associated with outcome [23–28]. The first part of this thesis focuses on the association of different injury mechanisms – including unique tibial plateau fracture patterns resulting from high- and low-energy traumas – and patient-reported functional outcomes **[PART I]**.

HOW ARE THEY TREATED

Tibial plateau fractures vary from relatively simple nondisplaced fractures to severely displaced multi-fragmentary fractures. One of the first medical documentations of these fractures was written by Sir Ashley Cooper in the book “A Treatise on Dislocation and Fractures of the Joints”, published in 1825 [29]. Before the existence of modern-day imaging techniques, the golden standard for diagnosing fractured bones was physical examination by palpation and manipulation. However, the discovery of X-ray technology by Wilhelm Conrad Röntgen (1845-1923) in 1895 revolutionized diagnostics by allowing visualization of bone without the need for surgical dissection of soft tissue. More than a century later, this method is still one of the most used imaging techniques in daily practice to diagnose a wide variety of medical conditions. In 1969, Godfrey Hounsfield (1919 – 2004) introduced computed tomography (CT), a technique that creates cross-sectional images, allowing multi-dimensional visualization of bones throughout the body. CT-scans are currently considered to be the golden standard for diagnosing these fractures. By the late 20th century, Magnetic Resonance Imaging (MRI) further expanded diagnostic capabilities by enabling better visualization of soft tissue injuries (e.g. ligaments, menisci and cartilage). The application of these different imaging techniques has improved our understanding of the complexity of tibial plateau fractures and provided opportunities to improve treatment.

There are at least 38 different classification methods described for tibial plateau fractures, all of which are based on plain radiographs or CT-scan images [30]. One of the first radiographic based classification methods stems from the beginning of the 20th century and was proposed by Marchant [31]. He described three different types of tibial plateau fractures: split fractures, articular depression fractures or a combination of both. At the end of the 20th century, Schatzker created a new radiographic based classification method and described six different fracture patterns (Figure 1) [32]. Type I split fractures, type II split fractures combined with an articular depression and type III articular depression fractures involve the lateral tibial plateau and often the result of low-energy trauma mechanisms. Type IV fractures are isolated fractures of the medial plateau. Type V and VI are fractures with involvement of both the lateral and medial tibial plateau. Type IV-VI fractures are more often the result of higher impact during high-energy trauma mechanisms [18,32]. The Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association (AO/OTA) classification system was later introduced, categorizing tibial plateau fractures in three different fracture types: 41A1-3, 41B1-3 and 41C1-3. Type 41A1-3 are extra articular fractures without involvement of the tibial plateau, type 41B1-3 includes partial articular fractures described as split fractures, articular depression fractures or a combination of a split and articular depression and type 41C1-3 consists of complete articular fractures divided in relatively simple to more complex multi-fragmentary patterns [2,33]. Although Schatzker and AO/OTA are still two of the most widely used classification methods worldwide, they rely on plain radiographs without considering the three-dimensional aspect of these fracture patterns, in particular fractures in the coronal plane – the so-called dorsal shear fractures. To address this limitation, Luo introduced the three-column concept in 2010, which is based on multiple plane CT-scan images [34]. He divided the tibial plateau in three different regions including lateral, medial and posterior. By incorporating CT-scan images, this concept adds more insight in the fracture mechanism and patterns.

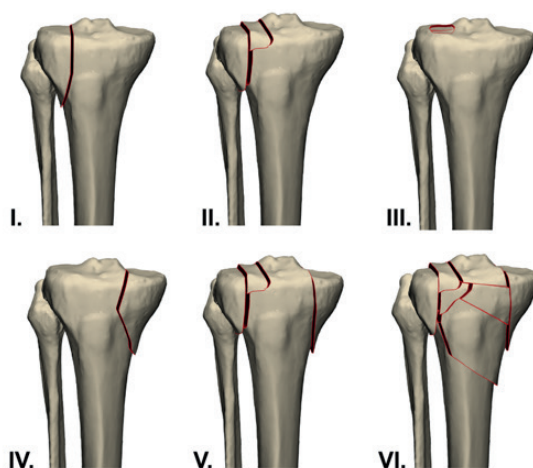


Figure 1 The Schatzker classification categorizes tibial plateau fractures into six different fracture types.

Radiographic measurements are performed to assess the fracture severity and include evaluation of both the intra-articular congruity and tibial alignment [35]. Gap and step-off measurements are used to assess the degree of initial fracture displacement and are main indicators when deciding between operative or nonoperative treatment [22,36]. The gap is the separation of fracture fragments along the articular surface, while step-off is the separation of fracture fragments perpendicular to the articular surface [37]. In case of operative treatment, the quality of the fracture reduction and tibial alignment are assessed by measuring the residual incongruence, condylar widening, medial proximal tibial angle (MPTA) and posterior proximal tibial angle (PPTA) on postoperative radiographs or CT-scan [38–41]. Residual incongruence is the maximum gap or step-off after fracture reduction. Condylar widening is the difference in width between the femoral condyles and the tibial plateau [40]. The MPTA is the angle of the tibial plateau relative to the tibia on the anteroposterior view and the PPTA is the angle of the tibial plateau relative to the tibia in the lateral view. The postoperative fracture reduction is described as adequate when both gap and step-off are ≤ 2 mm, condylar widening between 0-5 mm, MPTA between $87^\circ \pm 5^\circ$ and PPTA between $9^\circ \pm 5^\circ$ [38,39,41].

Based on the fracture classification, fracture displacement and preexisting comorbidities (e.g. osteoporosis), patients can be treated operatively or nonoperatively. Nonoperative treatment usually consists of long leg casting, hinged knee bracing, and restricted weight bearing, followed by gradual increase in range of motion and physiotherapy [2,19,42,43]. This type of treatment is mainly used for more simple, minimally displaced tibial plateau fractures. The overall aim in operative treatment of tibial plateau fractures is to restore articular congruity, reestablish joint stability, achieve normal axial and rotational alignment and early mobilization after surgery [22,25,43,44]. Operative treatment usually consists of percutaneous screw fixation, open reduction and internal fixation (ORIF) or external fixation. Percutaneous screw fixation is mainly used for more simple split or articular depression fractures of the lateral tibial plateau [36]. ORIF can be used for all types of fractures, varying from lateral to medial split fractures, articular depression fractures or combined split-depression fractures to bicondylar multi-fragmentary fractures. Realignment and stabilization of the fracture fragments is accomplished by using osteosynthesis material including screws and plates. External fixation is mainly used in polytrauma patients or when there is significant soft tissue damage due to the trauma and is meant to temporarily fixate the fracture before permanent fracture fixation [45]. The last method is primary total knee arthroplasty (TKA), which is sometimes used for complex fractures, particular in elderly patients with preexisting symptomatic osteoarthritis. For those patients, primary TKA may result in better outcomes compared to fracture fixation, since achieving adequate fracture reduction and maintaining stable fixation can be challenging due to their osteoporotic bone quality [46].

In general, the indication for operative treatment of tibial plateau fractures is an intra-articular gap or step-off above 2 mm [22,36]. Although Giannoudis et al. reported that gaps and step-offs up to 10 mm could be well tolerated and may be accepted for nonoperative treatment, it is widely believed that achieving anatomical fracture reduction < 2 mm is essential to achieve good functional outcomes [47]. However, these assumptions are based on studies conducted 30 years ago, with measurements performed on plain radiographs [44]. To this day, there is still limited evidence supporting this 2 mm cutoff as a critical threshold for achieving good functional outcomes [48]. Furthermore, the current practice of using CT-scans as the main basis for clinical decision-making renders it unclear whether the cutoff of 2 mm for operative treatment is still relevant today [36]. Besides the initial fracture displacement, postoperative fracture reduction, restoration of the tibial alignment and knee stability are generally believed to influence patient-reported functional outcomes [38]. Unfortunately, postoperative malreductions are relatively common, affecting more than 30% of operatively treated patients [49]. The initial fracture displacement, inadequate postoperative incongruity and tibial malalignment (sagittal and coronal) increase the risk of posttraumatic osteoarthritis and are strong predictors for conversion to TKA [35,50]. Despite these associations, the actual impact of initial fracture displacement and postoperative fracture reduction on the patient-reported functional outcome remain unclear. The second part of this thesis focuses on the extent to which initial fracture displacement can be accepted without compromising the patient-reported functional outcome after nonoperative treatment, evaluates whether the current indications for operative treatments of minimally displaced tibial plateau fractures are still justified, and assesses the association between pre- and postoperative radiographic measurements and recovery in terms of functional outcome [PART II].

HOW DO THEY RECOVER

When treating patients with tibial plateau fractures, one of the most important factors to consider is how they will recover after their treatment. In the short term, these injuries are mainly disabling due to immobilization or postoperative recovery, but in the long term, these patients have higher risks of posttraumatic osteoarthritis, chronic pain and knee stiffness or instability, which could result in conversion to TKA [22,51–54]. This affects the patient-reported functional outcome, and some studies report that the patient-reported outcome scores after tibial plateau fractures remain lower compared to those of the general population [25,55]. However, they only look at the outcomes of the entire population and do not distinguish in age. While for patients it is more interesting to know how they perform compared to age-related peers due to differences in level of activity, ambulatory status, preexisting comorbidities, and coping mechanisms between young and elderly. Yet, most patients report a decline in functional outcome in the first months

after a tibial plateau fracture, followed by a steep increase from 6 up to 12 months. The functional outcome still shows some increase after 5 years, but the average patient does not reach their pre-injury level [56]. Although the majority of patients is able to return to their previous work after a median incapacity of 120 days, more than 30% of patients will not resume sports, and among those who return, 40% will not reach their pre-injury level [26,57,58]. Even though patient-reported functional outcomes at 6 months are decreased compared to pre-injury scores and tend to increase between 6 and 12 months, it is currently unknown which domains (e.g. symptoms, pain, daily activities, sports, overall quality of life) are most affected within the first year. Understanding this is important to be able to adequately counsel patients during their treatment. Therefore, the last part of this thesis will focus on how patient-reported functional outcomes after tibial plateau fractures are related to those of the age-related peers from the general population and how the course of recovery progresses within the first year after the injury **[PART III]**.

AIMS OF THE THESIS

The overall aim of the research presented in this thesis is to get more insight in the patient-reported functional outcome of patients after tibial plateau fractures.

The specific aims are:

- To compare the functional outcome and complications in tibial plateau fractures caused by high- and low-energy trauma **[Chapter 2]**.
- To assess the relationship between the different unique tibial plateau injury mechanisms and the functional recovery at follow-up **[Chapter 3]**.
- To assess what sizes of gaps and step-offs could be accepted for nonoperative treatment of tibial plateau fractures **[Chapter 4]**.
- To compare functional outcome after nonoperative and operative treatment in minimally displaced tibial plateau fractures to address whether current indications for surgery are still justified **[Chapter 5]**.
- To assess the association between different radiographic features and recovery in terms of patient-reported outcome following surgical treatment of tibial plateau fractures **[Chapter 6]**.
- To assess the patient-reported functional outcome after tibial plateau fractures compared to outcome scores of age-related 'healthy' peers **[Chapter 7]**.
- To prospectively assess the course and level of recovery of patients during the first year following tibial plateau fractures **[Chapter 8]**.

REFERENCES

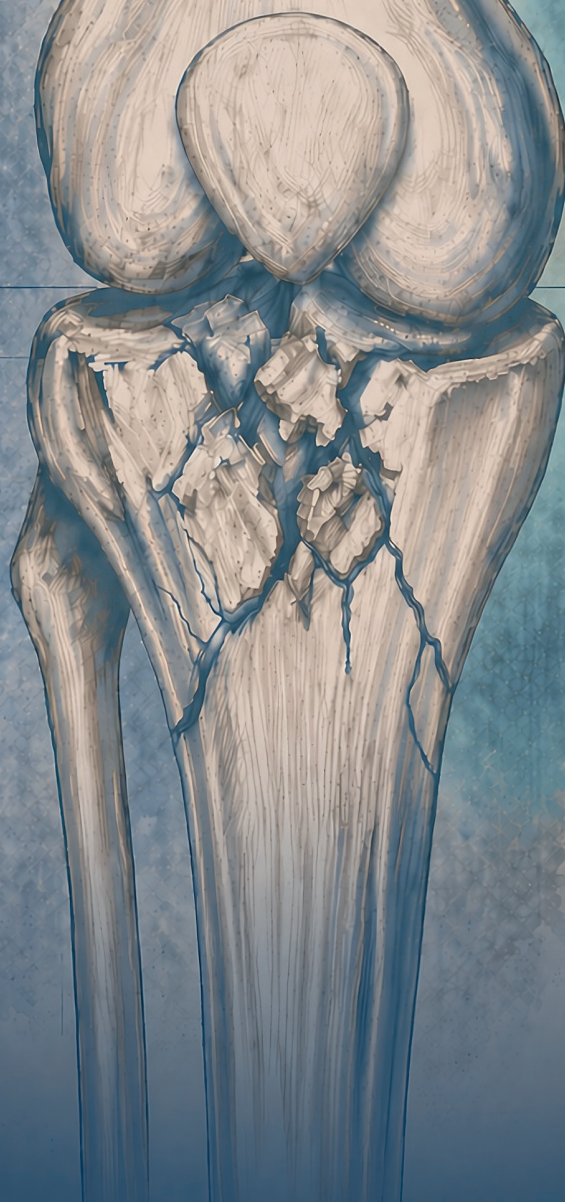
1. Kutzner I, Heinlein B, Graichen F, et al. Loading of the knee joint during activities of daily living measured in vivo in five subjects. *J Biomech.* 2010;43:2164–2173.
2. Rozell JC, Vemulapalli KC, Gary JL, Donegan DJ. Tibial plateau fractures in elderly patients. *Geriatr Orthop Surg Rehabil.* 2016;7:126–134.
3. Berkson EM, Virkus WW. High-energy tibial plateau fractures. *J Am Acad Orthop Surg.* 2006;14:20–31.
4. Abdel-Hamid MZ, Chang CH, Chan YS, et al. Arthroscopic evaluation of soft tissue injuries in tibial plateau fractures: Retrospective analysis of 98 cases. *Arthroscopy.* 2006;22:669–675.
5. Chang H, Zheng Z, Shao D, Yu Y, Hou Z, Zhang Y. Incidence and radiological predictors of concomitant meniscal and cruciate ligament injuries in operative tibial plateau fractures: A prospective diagnostic study. *Sci Rep.* 2018;8:13317.
6. Grawe B, Schroeder AJ, Kakazu R, Messer MS. Lateral collateral ligament injury about the knee: Anatomy, Evaluation, and Management. *J Am Acad Ortop Surg.* 2018;26:e120–e127.
7. Andrews K, Lu A, Mckean L, Ebraheim N. Review: Medial collateral ligament injuries. *J Orthop.* 2017;14:550–554.
8. Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Ménétrey J. Anatomy of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc.* 2006;14:204–213.
9. Pache S, Aman ZS, Kennedy M, et al. Posterior cruciate ligament: Current Concepts Review. *Arch Bone Jt Surg.* 2018;8:8–18.
10. Bryceland JK, Powell AJ, Nunn T. Knee Menisci. *Cartilage.* 2017;8:99–104.
11. Court-Brown CM, Caesar B. Epidemiology of adult fractures: A review. *Injury.* 2006;37:691–697.
12. Elsoe R, Larsen P, Nielsen NPH, Swenne J, Rasmussen S, Ostgaard SE. Population-based epidemiology of tibial plateau fractures. *Orthopedics.* 2015;38:e780–e786.
13. Herteleer M, Van Brandt C, Vandoren C, Nijs S, Hoekstra H. Tibial plateau fractures in Belgium: epidemiology, financial burden and costs curbing strategies. *Eur J Trauma Emerg Surg.* 2022;48:3643–3650.
14. Wennergren D, Bergdahl C, Ekelund J, Juto H, Sundfeldt M, Möller M. Epidemiology and incidence of tibia fractures in the Swedish fracture register. *Injury.* 2018;49:2068–2074.
15. World Health Organization. Ageing and health [Internet]. [cited 2025 Feb 17]. <https://www.who.int/news-room/fact-sheets/detail/ageing-and-health>. Accessed 17 Feb 2025.
16. Xie X, Zhan Y, Wang Y, Lucas JF, Zhang Y, Luo C. Comparative analysis of mechanism-associated 3-dimensional tibial plateau fracture patterns. *J Bone Joint Surg Am.* 2020;102:410–418.
17. Zhang BB, Sun H, Zhan Y, et al. Reliability and repeatability of tibial plateau fracture assessment with an injury mechanism-based concept. *Bone Joint Res.* 2019;8:357–366.
18. Kfuri M, Schatzker J. Revisiting the Schatzker classification of tibial plateau fractures. *Injury.* 2018;49:2252–2263.
19. Jeelani A, Arastu MH. Tibial plateau fractures – review of current concepts in management. *Orthop Trauma.* 2017;31:102–115.
20. Oladeji LO, Worley JR, Crist BD. Age-related variances in patients with tibial plateau fractures. *J Knee Surg.* 2020;33:611–615.

21. Donovan RL, Smith JRA, Yeomans D, Bennett F, White P, Chesser TJS. Epidemiology and outcomes of tibial plateau fractures in adults aged 60 and over treated in the United Kingdom. *Injury*. 2022;53:2219–2225.
22. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: An update. *EFORT Open Rev*. 2017;1:225–232.
23. Weigel DP, Marsh JL. High-energy fractures of the tibial plateau: Knee function after longer follow-up. *J Bone Joint Surg Am*. 2002;84:1541–1551.
24. Evangelopoulos D, Chalikias S, Michalos M, et al. Medium-term results after surgical treatment of high-energy tibial plateau fractures. *J Knee Surg*. 2020;33:394–398.
25. Timmers TK, van der Ven DJC, de Vries LS, van Olden GDJ. Functional outcome after tibial plateau fracture osteosynthesis: a mean follow-up of 6 years. *Knee*. 2014;21:1210–1215.
26. Hap DXF, Kwek EBK. Functional outcomes after surgical treatment of tibial plateau fractures. *J Clin Orthop Trauma*. 2020;11:S11–S15.
27. Assink N, Kraeima J, Meesters AML, et al. 3D assessment of initial fracture displacement of tibial plateau fractures is predictive for risk on conversion to total knee arthroplasty at long-term follow-up. *Eur J Trauma Emerg Surg*. 2023;49:867–874.
28. Assink N, Bosma E, Meesters AML, et al. Initial and residual 3D Fracture displacement is predictive for patient-reported functional outcome at mid-term follow-up in surgically treated tibial plateau fractures. *J Clin Med*. 2023;12:6055.
29. Sir A. Cooper. *A Treatise on Dislocations and on Fractures of the Joints*. 1824.
30. Millar SC, Arnold JB, Thewlis D, Fraysse F, Solomon LB. A systematic literature review of tibial plateau fractures: What classifications are used and how reliable and useful are they? *Injury*. 2018;49:473–490.
31. Gerard-Marchant P. Fractures des plateaux tibiaux. *Rev Chir Orthop*. 1939;26:499–546.
32. Schatzker J, McBroom R. The tibial plateau fracture. The Toronto experience 1968-1975. *Clin Orthop Relat Res*. 1979;138:94–104.
33. Müller ME, Koch P, Nazarian S, Schatzker J. *The comprehensive classification of fractures of long bones*. Springer Berlin Heidelberg; 1990.
34. Wang Y, Luo C, Zhu Y, et al. Updated Three-Column concept in surgical treatment for tibial plateau fractures - A prospective cohort study of 287 patients. *Injury*. 2016;47:1488–1496.
35. Assink N, Moumni M El, Kraeima J, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery results in a large multicenter cohort. *J Bone Joint Surg Am*. 2023;105:1237–45.
36. Pelser P. Controversies in the management of tibial plateau fractures. *SA Orthopaedic Journal*. 2010;9:75–82.
37. Vaartjes TP, Assink N, Nijveldt RJ, et al. Functional outcome after nonoperative management of tibial plateau fractures in skeletally mature patients: What sizes of gaps and stepoffs can be accepted? *Clin Orthop Relat Res*. 2022;480:2288–2295.
38. Barei DP, Nork SE, Mills WJ, Coles CP, Henley MB, Benirschke SK. Functional outcomes of severe bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plates. *J Bone Joint Surg Am*. 2006;88:1713–1721.

39. Barei DP, Nork SE, Mills WJ, Bradford Henley M, Benirschke SK. Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. *J Orthop Trauma*. 2004;18:649–657.
40. Johannsen AM, Cook AM, Gardner MJ, Bishop JA. Defining the width of the normal tibial plateau relative to the distal femur: Critical normative data for identifying pathologic widening in tibial plateau fractures. *Clin Anat*. 2018;31:688–692.
41. Van den Berg J, De Boer AS, Assink N, et al. Trauma mechanism and patient reported outcome in tibial plateau fractures with posterior involvement. *Knee*. 2021;30:41–50.
42. Rudran B, Little C, Wiik A, Logishetty K. Tibial plateau fracture: Anatomy, diagnosis and management. *Br J Hosp Med (Lond)*. 2020;81:1–9.
43. Mthethwa J, Chikate A. A review of the management of tibial plateau fractures. *Musculoskeletal Surg*. 2018;102:119–127.
44. Tscherne H, Lobenhoffer P. Tibia plateau fractures management and expected Results. *Clin Orthop Relat Res*. 1993;(292):87–100.
45. Malik S, Herron T, Mabrouk A, Rosenberg N. Tibial plateau fractures. [Internet]. 2023 [cited 2025 Feb 25]. <https://www.ncbi.nlm.nih.gov/books/NBK470593/>. Accessed 25 Feb 2025
46. Parratte S, Ollivier M, Argenson JN. Primary total knee arthroplasty for acute fracture around the knee. *Orthop Traumatol Surg Res*. 2018;104(1S):S71–S80.
47. Giannoudis P V., Tzioupis C, Papathanassopoulos A, Obakponovwe O, Roberts C. Articular step-off and risk of post-traumatic osteoarthritis. Evidence today. *Injury*. 2010;41:986–995.
48. Marsh JL, Buckwalter J, Gelberman R, Dirschl D, Olson S, Brown T, et al. Articular fractures: Does an anatomic reduction really change the result? *J Bone Joint Surg Am*. 2002;84;1259–1271.
49. Meulenkamp B, Martin R, Desy NM, Duffy P, Korley R, Puloski S, et al. Incidence, risk factors, and location of articular malreductions of the tibial plateau. *J Orthop Trauma*. 2017;31:146–150.
50. Parkkinen M, Madanat R, Mustonen A, Koskinen SK, Paavola M, Lindahl J. Factors predicting the development of early osteoarthritis following lateral tibial plateau fractures: mid-term clinical and radiographic outcomes of 73 operatively treated patients. *Scand J Surg*. 2014;103:256–262.
51. Papagelopoulos PJ, Partsinevelos AA, Themistocleous GS, Mavrogenis AF, Korres DS, Soucacos PN. Complications after tibia plateau fracture surgery. *Injury*. 2006;37:475–484.
52. Manidakis N, Dosani A, Dimitriou R, Stengel D, Matthews S, Giannoudis P. Tibial plateau fractures: Functional outcome and incidence of osteoarthritis in 125 cases. *Int Orthop*. 2010;34:565–570.
53. Wasserstein D, Henry P, Paterson JM, Kreder HJ, Jenkinson R. Risk of total knee arthroplasty after operatively treated tibial plateau fracture. *J Bone Joint Surg Am*. 2014;96:144–150.
54. Scott CEH, Davidson E, Macdonald DJ, White TO, Keating JF. Total knee arthroplasty following tibial plateau fracture: A matched cohort study. *Bone Joint J*. 2015;97:532–538.
55. 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;41:1865–1873.
56. Ramoutar DN, Lefavre K, Broekhuysen H, Guy P, O'Brien P. Mapping recovery in simple and complex tibial plateau fracture fixation. *Bone Joint J*. 2019;101-B:1009–1014.
57. Kraus TM, Abele C, Freude T, et al. Duration of incapacity of work after tibial plateau fracture is affected by work intensity. *BMC Musculoskeletal Disord*. 2018;19:281.
58. Robertson GAJ, Wong SJ, Wood AM. Return to sport following tibial plateau fractures: A systematic review. *World J Orthop*. 2017;8:574–587.

TIBIAL PLATEAU
FRACTURE

ANTERIOR VIEW



PART I

How do they occur

Chapter 2



**What is the patient-reported outcome,
complication rate and conversion to total knee
arthroplasty in patients with tibial plateau fractures
caused by high-energy compared to low-energy
mechanisms of injury?**

Thijs P. Vaartjes, Tijmen W. Kraai, Eelke Bosma,
Fabian J. van der Sluis, Joost G. ten Brinke, Reinier de Groot,
Harm Hoekstra, Job N. Doornberg, Nick Assink, Frank F.A. IJpma

This chapter was published in:
European Journal of Trauma and Emergency Surgery (2025) 51:160
DOI: 10.1007/s00068-025-02810-0

ABSTRACT

Purpose Despite varying impact of high- and low-energy traumas, research comparing patient and fracture characteristics as well as patient-reported functional outcomes following these trauma mechanisms is limited. From a patient, doctor, and legal perspective, assessing the association between trauma mechanism and clinical outcome is important for managing expectations.

Methods A multicenter cross-sectional study was performed including 1066 patients treated for a tibial plateau fracture between 2003 and 2019. Patients completed the Knee injury and Osteoarthritis Outcomes Score (KOOS) at a mean follow-up of 6 ± 4 years. Trauma mechanisms were classified according to ATLS guidelines. Independent-samples t-test and chi-square test were used to assess differences in patient and fracture characteristics after high- or low-energy trauma. Linear regression analyzed the relationship between trauma mechanisms and KOOS-scores. The Fisher's exact assessed differences in complications and conversion to total knee arthroplasty (TKA).

Results High-energy trauma mostly occurred in younger males and low-energy trauma in older females. High-energy trauma caused more Schatzker IV-VI fractures, resulted in more initial fracture displacement and needed more often surgical treatment (81% versus 67%; $p = 0.002$). Linear regression showed that high-energy trauma was associated with lower KOOS-scores. Patients after high-energy trauma had more complications (e.g. revision surgery [8% versus 2%; $p < 0.001$], mal- or nonunion [8% versus 2%; $p < 0.001$]) and conversion to TKA (15% versus 10%; $p = 0.144$).

Conclusion Only 12% of patients with tibial plateau fractures sustained these injuries due to high-energy trauma, which predominantly involved younger males and resulted in more severe fractures. High-energy trauma resulted in worse patient-reported outcomes, more complications, and conversions to TKA.

INTRODUCTION

Tibial plateau fractures, caused by both high- and low-energy trauma mechanisms, account for approximately 1-2% of all fractures [1]. Fractures caused by high-energy trauma usually occur due to motorized vehicles accidents or falls from height, whereas low-energy tibial plateau fractures often occur from bicycle accidents or a fall from standing height [2–4]. High-energy traumas might cause more complex fractures, often combined with severe soft tissue injury impairing functional outcomes [3, 5, 6]. Low-energy trauma often results in relatively simple fractures, however in older aged patients, complex fracture patterns are also seen after low-energy trauma because of age-related osteoporotic bone structure [3, 7–9]. Despite differences in impact of these trauma mechanisms there is limited research available that compares the patient and fracture characteristics, as well as patient-reported functional outcome after high- or low- energy traumas.

From patient-, doctor-, and legal perspectives, trauma mechanism might be of importance for treatment and recovery expectations. In general, worse outcomes could be expected after high-energy trauma mechanisms, as substantial force striking the knee can cause significant damage to cartilage, bone and soft tissues in these types of injuries. However, study findings regarding outcome after high- or low-energy trauma are inconclusive. Some studies indicate that high-energy traumas are associated with good or satisfactory patient outcome [10, 11], while others suggest it results in worse patient-reported outcomes at follow-up [12, 13]. Most studies on tibial plateau fractures do not consider the trauma mechanism as a factor associated with outcome [14–17]. These studies report outcomes for the entire study population, without taking into account the amount of energy that caused the injury. We hypothesized that patients with high-energy trauma have different patient characteristics, fracture types and prognosis than those with low-energy trauma. To adequately inform patients during counseling regarding their prognosis after high- or low-energy trauma, it is important to assess if there are differences in patient and fracture characteristic and whether the trauma mechanism influences the clinical outcome.

We therefore asked: (1) What are the differences in patient and fracture characteristics in patients with tibial plateau fractures caused by high- or low-energy trauma mechanisms? (2) What are the differences in clinical out- comes (i.e. patient-reported outcome, complications and conversion to total knee arthroplasty) between patients with tibial plateau fractures caused by high- versus low-energy trauma mechanism?

METHOD

Study design and setting

A multicenter cross-sectional study was performed on all patients with tibial plateau fractures who were treated between January 2003 and December 2019 at the University Medical Center Groningen (The Netherlands), Isala hospitals (The Netherlands), Gelre hospitals (The Netherlands), Martini hospital (The Netherlands), Medical Spectrum Twente (The Netherlands) and University Hospitals Leuven (Belgium). These include four Level 1 trauma centers and two Level 2 trauma centers. The study procedure was approved in all participating centers by the institutional review board (research number: 201800411) and was performed in accordance with the relevant guidelines and regulations. This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline [18].

Participants

All patients of 18 years and older, treated for tibial plateau fractures, who had a diagnostic CT-scan, that were still alive and had at least 1 year of follow-up were considered eligible for inclusion. The exclusion criteria included, preexisting comorbidities of the injured leg, unknown trauma mechanism, patients with no knowledge of the Dutch language and patients with an unknown residential address.

Patient-reported outcomes

All eligible patients were asked to complete the standardized Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire [19]. In addition, patients were asked whether they underwent conversion to a total knee arthroplasty (TKA). KOOS is a validated questionnaire consisting of five subscales: symptoms, pain, activities of daily living (ADL), function in sports and recreation, and knee-related quality of life (QoL) [19]. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) was calculated for each subscale. Patients who had conversion to TKA were assigned an average KOOS score that was reported in a previous cohort of patients with KOOS scores before conversion to TKA [20]. These scores represent the situation as it was before conversion to TKA. The assumed KOOS sub-scores were 52 for symptoms, 45 for pain, 55 for ADL, 16 for sport and 27 for QoL. The minimal clinically important difference of each KOOS subscale is 9 for symptoms, 12 for pain, 10 for ADL, 9 for sports, and 14 for QoL [21].

Trauma mechanism

Patients were divided into two groups based on the energy of the trauma mechanism: high-energy (HET) and low-energy trauma (LET). The trauma mechanisms of all patients were reassessed through consensus by three observers (TPV, TWK, FFAIJ). The energy of

the trauma mechanism was defined according to the criteria of the Advanced Trauma Life Support (ATLS) guidelines (appendix 1) [22]. Patients who met at least one of these criteria were classified as high-energy trauma.

Data sources and measurements

Baseline characteristics, treatment (surgical or nonsurgical), trauma mechanism, injury severity scores (ISS), and associated injuries were retrieved from the patients' electronic records. All knee radiographs and CT images were reassessed through consensus by two observers (TPV, FFAIJ) with experience in tibial plateau fracture management according to the Schatzker classification systems [23]. Gap and step-off measurements were performed on CT images to describe the fracture displacement. Gap was defined as separation of fracture fragments along the articular surface and step-off as separation of fracture fragments perpendicular to the articular surface [16]. The maximum gap and step-off were measured by going through axial, coronal and sagittal CT slices. The scores from each subscale of the KOOS questionnaire were calculated from the patient survey of the responding patients.

Primary and secondary study outcomes

The primary study goal was to determine whether there were differences in patient and fracture characteristics between patients with a tibial plateau fracture after high- or low-energy trauma. The secondary goal was to assess whether there were differences in mid-term clinical outcomes after high- versus low-energy trauma in terms of patient-reported functional outcome, complications (e.g. reoperations, revision surgery) and conversion to TKA during follow-up.

Statistical analysis

SPSS software (version 28, IBM Corp) was used for statistical analyses. Continuous variables are presented as the mean and standard deviation (SD) for normally distributed data and median and IQR for nonnormally distributed data. First, the study population was divided into two groups based on trauma mechanism (high- or low-energy). Descriptive statistics were used to describe the study population, and we used independent-samples t-test for continuous variables and chi-square test for noncontinuous variables to assess differences between the groups in terms patient and fracture characteristics. For sub-analysis, the study population after high- or low-energy trauma was divided in groups based on the patients age (≤ 50 and ≥ 51), because from the age of 50 the prevalence of osteoporosis is increasing [24, 25]. We used independent-samples t-test for continuous variables and chi-square test for noncontinuous variables to assess differences in fracture characteristics between young and older aged patients. Secondly, we used linear regression to analyze the relationship between the trauma mechanism and KOOS score. The model was adjusted

for five potential confounders, including age, sex, BMI, smoking and diabetes. A Fisher's exact test was used for the noncontinuous variables to assess differences in complications and conversion to TKA between patients after high- and low-energy trauma. Significance level was set at $p < 0.05$.

Analysis of the nonparticipants

For the nonresponse analysis, we used an independent-samples t-test for continuous variables and a chi-square test for noncontinuous variables. The nonresponse analysis showed that responders were slightly older than nonresponders (53 ± 15 years versus 51 ± 17 years; $p = < 0.001$). There was not much difference in sex between responders and nonresponders (female 68% [725 of 1066] versus female 58% [518 of 890]; $p = < 0.001$). Due to data protection and privacy legislation as well as medical ethical reasons, knee radiographs and CT images of the nonresponders were only available in the initiating center and one affiliated center ($n=545$). There was no difference in fracture classification between responders and nonresponders (Schatzker I [11% versus 12%], Schatzker II [31% versus 27%], Schatzker III [17% versus 18%], Schatzker IV [13% versus 16%], Schatzker V [8% versus 6%], Schatzker VI [20% versus 21%] $p = 0.778$).

RESULTS

A total of 2175 patients were treated for a tibial plateau fracture between 2003 and 2019. Of these patients, 93 had preexisting comorbidities of the injured leg, 35 had unknown trauma mechanism, 31 had no knowledge of the Dutch language and 60 had an unknown address, leaving 1956 patients for follow-up analysis. All eligible patients were contacted by posted mail from which 54% (1066 of 1956) responded at a mean follow-up of 6 ± 4 years. The mean age at the time of injury was 53 ± 15 years and 68% (725 out of 1066) of patients were female (Fig. 1).

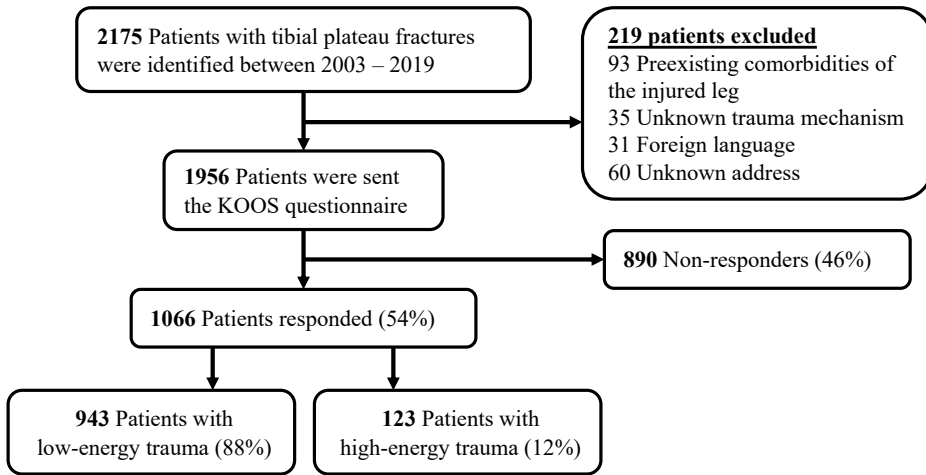


Figure 1 Patient inclusion and exclusion flow chart.

Difference in patient and fracture characteristics between high and low energy traumas

Between 2003 and 2019, 12% [123 out of 1066] of patients with tibial plateau fractures sustained their injuries due to high-energy trauma. High-energy traumas were mainly caused by road traffic accidents, whereas low-energy traumas were mainly caused by low energy falls and bicycle accidents (Table 1). High-energy trauma mostly occurred in younger males and low-energy trauma in older females (appendix 2). High-energy trauma caused more severe Schatzker IV-VI fractures (IV [27% versus 13%; $p < 0.001$], V [14% versus 6%; $p = 0.002$] and VI [24% versus 13%; $p = 0.003$]). Low-energy trauma caused more Schatzker II and III fractures (II [37% versus 23%; $p = 0.002$] and III [24% versus 10%; $p < 0.001$]). High-energy trauma resulted in more initial fracture displacement compared to low-energy trauma (gap [5.2 ± 5.5 versus 6.7 ± 5.7 ; $p = 0.009$], step-off [5.9 ± 5.9 versus 7.6 ± 7.0 ; $p = 0.005$]). Patients received more frequently surgical treatment after high-energy trauma compared to low-energy trauma (81% versus 67%; $p = 0.002$). High-energy trauma resulted in a higher prevalence of concomitant injuries (40% [49 of 123] versus 7% [62 of 943]; $p < 0.001$) (Table 1). The sub-analysis between young and older aged patients showed that low-energy trauma resulted in significantly more Schatzker VI fractures in the older aged patient population compared to the younger patients (16% versus 6%; $p < 0.001$) (Table 2).

Table 1 Differences in patient and fracture characteristics between high- and low- energy trauma

Patient characteristics	LET (n= 943)	HET (n=123)	P-value
Age (years)	54 ± 15	48 ± 15	< 0.001
Female	682 (72)	43 (35)	< 0.001
BMI (kg/m ²)	26.4 ± 4.7	26.6 ± 5.1	0.606
Smoking	193 (21)	19 (16)	0.167
Diabetic	78 (9)	7 (6)	0.295
Schatzker classification			
Schatzker I	71 (8)	4 (3)	0.091
Schatzker II	345 (37)	28 (23)	0.002
Schatzker III	231 (25)	12 (10)	< 0.001
Schatzker IV	119 (13)	33 (27)	< 0.001
Schatzker V	54 (6)	17 (14)	0.002
Schatzker VI	123 (13)	29 (24)	0.003
Initial fracture displacement			
Gap (mm)	5.2 ± 5.5	6.7 ± 5.7	0.009
Step-off (mm)	5.9 ± 5.9	7.6 ± 7.0	0.005
Treatment			
Surgical	627 (67)	99 (81)	0.002
Injury characteristics			
Left side	559 (59)	68 (55)	0.397
ISS			
>16	0 (0)	14 (11)	< 0.001
Concomitant injuries			
Head	8 (1)	18 (15)	< 0.001
Chest	7 (1)	18 (15)	< 0.001
Abdomen	1 (0)	3 (3)	< 0.001
Pelvis	1 (0)	5 (4)	< 0.001
Upper limb	25 (3)	19 (15)	< 0.001
Lower limb	20 (2)	18 (15)	< 0.001
Trauma mechanism			< 0.001
Low- energy fall	456 (48)	0 (0)	
High- energy fall	0 (0)	4 (3)	
RTA*- pedestrian	26 (3)	11 (9)	
RTA- bicyclist	298 (32)	26 (21)	
RTA- scooter	42 (5)	24 (20)	
RTA- motorbike	14 (2)	33 (27)	
RTA- MVA	2 (0)	15 (12)	
Sports injury	73 (8)	5 (4)	
Other	32 (3)	5 (4)	
Follow-up (years)	6 ± 4	7 ± 4	0.257

Numbers are presented as mean ± standard deviation or as number and percentage (%).

*RTA is road traffic accident.

Table 2 Fracture characteristics of the young and older aged patients

Fracture characteristics	LET (n=943)		P-value	HET (n=123)		P-value
Age group	≤ 50 (n=300)	≥ 51 (n=643)		≤ 50 (n=65)	≥ 51 (n=58)	
Schatzker classification						
Schatzker I	37 (12)	34 (5)	< 0.001	2 (3)	2 (3)	0.908
Schatzker II	107 (36)	238 (37)	0.689	12 (19)	16 (28)	0.283
Schatzker III	72 (24)	159 (25)	0.809	7 (11)	5 (9)	0.689
Schatzker IV	51 (17)	68 (11)	0.006	17 (26)	16 (28)	0.858
Schatzker V	16 (5)	38 (6)	0.723	9 (14)	8 (14)	0.993
Schatzker VI	17 (6)	106 (17)	< 0.001	18 (28)	11 (19)	0.255

Numbers are presented as mean ± standard deviation or as number and percentage (%).

Differences in clinical outcome after high or low-energy trauma

Clinical outcome is subdivided in patient-reported outcome, complications (e.g. reoperations or revision surgery), and conversion to total knee arthroplasty. First of all, tibial plateau fractures resulted in worse patient-reported functional outcome after high-energy trauma. KOOS scores after high-energy or low-energy trauma differ in symptoms (71 ± 21 versus 76 ± 21 ; $p = 0.008$), pain (72 ± 23 versus 77 ± 22 ; $p = 0.044$) and QoL (51 ± 28 versus 59 ± 28 ; $p = 0.005$) except for sport (41 ± 34 versus 48 ± 34 ; $p = 0.051$) and ADL (76 ± 20 versus 79 ± 21 ; $p = 0.068$). After correction for potential confounders including age, sex, BMI, smoking and diabetes, linear regression showed that high-energy trauma mechanism was associated with lower KOOS scores for each of the five subscales of the KOOS questionnaire (Table 3). Secondly, patients after high-energy trauma had more reoperations, revision surgeries, and mal- or nonunions of the tibial plateau. Eventually, there was a slight difference in conversion to TKA after high- compared to low-energy trauma (15% versus 10%; $p = 0.144$) (Table 4).

Table 3 High-energy trauma associated with lower patient-reported outcome, a multivariate analysis

KOOS subscale	β^a	95% CI	P-value
Symptoms	-7.1	-11.1 – -3.0	< 0.001
Pain	-7.0	-11.3 – -2.6	< 0.001
ADL	-6.7	-10.7 – -2.7	< 0.001
Sport	-11.7	-18.5 – -4.9	< 0.001
QoL	-9.5	-15.0 – -4.0	< 0.001

^aAdjusted for potential confounders including age, sex, BMI, smoking and diabetes.

Table 4 High-energy trauma associated with more reoperations and complications

Reoperations and Complications	Total	LET	HET	P-value
Removal of osteosynthesis material	327 (31)	270 (29)	57 (46)	< 0.001
Reoperation for fracture-related infection	32 (3)	28 (3)	4 (3)	0.780
Reoperation for meniscal or ligamentous repair	30 (3)	23 (2)	7 (6)	0.072
Revision surgery for residual replacement	25 (2)	15 (2)	10 (8)	< 0.001
Malunion or nonunion	29 (3)	19 (2)	10 (8)	< 0.001
Conversion to Total Knee Arthroplasty	115 (11)	97 (10)	18 (15)	0.163

Numbers are presented as number and percentage (%).

DISCUSSION

Despite the different impact of high- and low-energy trauma mechanisms, there is limited research available which compares the difference in patient characteristic, fracture types, and clinical outcome associated with these different levels of energy causing these injuries. To adequately counsel patients regarding their prognosis following high- or low-energy trauma, it is important to understand whether the type of injury influences the outcome. We evaluated a large cohort of patients with tibial plateau fractures after both high- and low-energy trauma to assess whether there are differences between these groups. First of all, our results showed that high-energy traumas mostly occurred in younger males and caused more severe fractures according to the Schatzker classification whereas low-energy trauma mostly occurred in older females [23]. Furthermore, Schatzker VI fractures occurred in 1 out of 6 older aged patients after low-energy trauma, compared to 1 out of 17 in younger patients. This indicates that older patients, who may have more osteoporotic bone, tend to experience more severe fracture patterns despite low-energy trauma. Secondly, our study demonstrated that the clinical outcome in terms of patient-reported functional outcome is slightly worse after high-energy trauma, but within the range of the minimal clinically important difference. The complication rate, however, is higher after high-energy trauma. The conversion rate to TKA is slightly higher after high-energy compared to low energy trauma (15% versus 10%). Based on these findings, we believe that patients, surgeons, and insurance companies should be aware that high-energy tibial plateau fractures account for only $\pm 12\%$ of all tibial plateau fractures but should be considered challenging injuries with worse outcome.

Differences in patient and fracture characteristics after high- versus low-energy tibial plateau fractures

Tibial plateau fractures result from various high- and low-energy trauma mechanisms. Our study showed that high-energy traumas were mostly caused due to road traffic accidents (e.g. motorbike, scooter and bicyclist) and low-energy traumas due to low

energy falls (e.g. fall from standing height) and bicycle accidents. High-energy traumas occurred more often in younger males and low-energy traumas in older females. Similar results are shown in a population-based study of Elsoe et al. who also reported that high-energy trauma occurred more often in younger patients and low-energy trauma in older females [3]. However, they describe an equally distribution of males and females with high-energy traumas in the younger aged population, while our data indicated these cases were predominantly males. Furthermore, our results showed that high-energy trauma more often caused severe Schatzker IV-VI fracture patterns and low-energy trauma mostly Schatzker II & III fractures. This corresponds to literature on tibial plateau fractures, which often classifies Schatzker I-III as low-energy fractures and more complex Schatzker IV-VI as high-energy fractures [2, 5, 6, 9]. Moreover, our study revealed that low-energy trauma caused more severe fracture patterns in older aged patients than in younger patients. Severe Schatzker VI fractures occurred in 16% of older aged patients with low-energy traumas, compared to 6% in younger patients. This finding is in line with other recent studies describing complex fracture patterns in older aged patients after low-energy trauma mechanism due to age related changes in bone structure (e.g. osteoporosis and osteoarthritis) [4, 7, 9]. Overall, high-energy traumas occur mostly in young males and result in more severe fracture patterns, whereas low-energy traumas are more common in older females but can result in severe fracture patterns as well, probably due to age-related decrease in bone density.

Differences in clinical outcome after high- versus low-energy tibial plateau fractures

Research regarding differences in clinical outcome of patients with tibial plateau fractures after high- or low-energy trauma is limited. We found that high-energy trauma mechanisms resulted in worse patient-reported functional outcome (KOOS). However, the difference in scores remained within the range of the minimum clinically important difference except for sport (B of -11.7 [95% CI: $-18.5 - -4.9$]; $p = < 0.001$) [21]. This suggests that while high-energy trauma leads to poorer functional outcomes, the impact on patient-reported outcomes is not beyond the threshold considered clinically significant. Furthermore, our study showed more complications (e.g. reoperations and revision surgery) after high-energy traumas, due to more complex fractures and extensive soft tissue damage. There was no substantial difference in rate of conversion to TKA between high- and low-energy trauma, although the percentage of TKA following high-energy trauma was slightly higher (15% versus 10%). To put this into perspective, the primary indication for TKA is elderly patients with degenerative or post-traumatic osteoarthropathy. In general, surgeons are more conservative in recommending TKA for younger patients due to the limited lifespan of prostheses caused by polyethylene wear. Therefore, a higher rate of conversion to TKA after high-energy trauma, primarily affecting younger patients, highlights the severity

of such injuries and their worse outcomes compared to low-energy traumas. Literature comparing clinical outcome after high- versus low-energy trauma in tibial plateau fracture management is scarce. Timmer et al. assessed the functional outcome after tibial plateau fracture osteosynthesis in a small retrospective cohort of 82 patients [12]. Their study presented some preliminary results that high-energy trauma patients had worse patient-reported outcomes (KOOS pain and quality of life). However, their study had a limited small sample size and did not include patients who underwent conversion to TKA in the analyses between high- and low-energy trauma patients. The study of Assink et al. reported similar results regarding complications during follow-up and showed that 14% had conversion to TKA [26]. However, this studies only assessed surgically treated patients and did not distinguish between high- and low-energy trauma when reporting complications and conversion to TKA. The risk of conversion to TKA in the current literature range from 0 to 21% [27], which may be due to differences in study populations (e.g. case mix and variations in indications for TKA). It is therefore difficult to directly compare our results with other studies. However, a recent study demonstrated that increase of fracture displacement, as measured in 3D, is associated with conversion to TKA [14]. This means that severe fracture patterns, more often seen in relatively younger individuals following high-energy trauma, eventually have higher risks of conversion to TKA as they age. When treating patients after high-energy trauma it is important to understand that this could potentially result in worse patient-reported functional outcomes and more complications (e.g. reoperations and revision surgery).

Limitations

This study has some response bias, which is inherent to the cross-sectional study design caused by loss of follow-up and nonresponse [28]. By approaching all eligible patients' multiple times, we attempted to reduce this risk as much as possible. The response rate of 54% is relatively high considering the mean follow-up of 6 years and is in line with what could be expected according to literature on postal survey studies [29]. On the other hand, this is one of the largest multicenter studies comparing patient characteristics, fracture types, and clinical outcome after both high- and low-energy trauma, including over 1000 patients with tibial plateau fractures. The nonresponse analysis showed only minor differences in terms of age, sex and fracture classification between the responders and non-responders, which is unlikely to affect our findings. Another limitation was the high variation in follow-up time, which ranged from 1 to 17 years (mean 6 ± 4) and is inherent to the cross-sectional study design. Therefore, our findings regarding clinical outcome between patients after high- or low-energy trauma mechanism are applicable for midterm follow-up but should be interpreted with caution regarding long-term follow-up (20 + years). Furthermore, the quality of fracture reduction was not considered when interpreting patient-reported outcome scores and the complication rate during follow-up.

Lastly, high-energy trauma caused more concomitant injuries, which is according clinical practice but could have influenced the patient-reported functional outcomes.

Conclusion

Only 12% of tibial plateau fractures were caused by high-energy traumas, typically affecting younger males in road traffic accidents. Low-energy traumas mostly occurred in older females from low energy falls and bicycle accidents. High-energy trauma resulted in more severe fracture patterns, although similar fracture patterns were seen in older patients after low-energy trauma, likely due to age-related decrease in bone density. High-energy trauma resulted in slightly worse patient-reported functional outcome, although these differences did not exceed the minimal clinically important difference except for sport. Furthermore, it resulted in more complications due to the complex fractures and extensive soft tissue injury. There was no substantial difference in conversion to TKA between patients after high- or low-energy trauma. Physicians, surgeons, rehabilitation doctors, and even legal personnel should be aware that management of patients with tibial plateau fractures after high-energy trauma is challenging, may require some dedicated teams and could result in worse clinical outcome. Future, large prospective studies are needed for personalized risk stratification and patients counselling after high- or low-energy trauma to further facilitate the shared-decision making process.

REFERENCES

1. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. *Injury*. 2006;37:691–7.
2. Jeelani A, Arastu MH. Tibial plateau fractures – review of current concepts in management. *Orthop Trauma*. 2017;31:102–15.
3. Elsoe R, Larsen P, Nielsen NPH, Swenne J, Rasmussen S, Ostgaard SE. Population-based epidemiology of tibial plateau fractures. *Orthopedics*. 2015;38:e780–e786.
4. Oladeji LO, Worley JR, Crist BD. Age-related variances in patients with tibial plateau fractures. *J Knee Surg*. 2020;33:611–615.
5. Berkson EM, Virkus WW. High-energy tibial plateau fractures. *J Am Acad Orthop Surg*. 2006;14:20–31.
6. Kfuri M, Schatzker J. Revisiting the schatzker classification of tibial plateau fractures. *Injury*. 2018;49:2252–2263.
7. Rozell JC, Vemulapalli KC, Gary JL, Donegan DJ. Tibial plateau fractures in elderly patients. *Geriatr Orthop Surg Rehabil*. 2016;7:126–134.
8. Donovan RL, Smith JRA, Yeomans D, Bennett F, White P, Chesser TJS. Epidemiology and outcomes of tibial plateau fractures in adults aged 60 and over treated in the United Kingdom. *Injury*. 2022;53:2219–2225.
9. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. *EFORT Open Rev*. 2017;1:225–232.
10. Weigel DP, Marsh JL. High-energy fractures of the tibial plateau: knee function after longer follow-up. *J Bone Joint Surg Am*. 2002;84:1541–1551.
11. Evangelopoulos D, Chalikias S, Michalos M, Vasilakos D, Pappa E, Zisis K, et al. Medium-term results after surgical treatment of high-energy tibial plateau fractures. *J Knee Surg*. 2020;33:394–398.
12. Timmers TK, van der Ven DJC, de Vries LS, van Olden GDJ. Functional outcome after tibial plateau fracture osteosynthesis: a mean follow-up of 6years. *Knee*. 2014;21:1210–1215.
13. Hap DXF, Kwek EBK. Functional outcomes after surgical treatment of tibial plateau fractures. *J Clin Orthop Trauma*. 2020;11:S11–S15.
14. Assink N, Kraeima J, Meesters AML, El Mounni M, Bosma E, Nijveldt RJ, et al. 3D assessment of initial fracture displacement of tibial plateau fractures is predictive for risk on conversion to total knee arthroplasty at long-term follow-up. *Eur J Trauma Emerg Surg*. 2023;49:867–874.
15. Assink N, Bosma E, Meesters AML, van Helden SH, Nijveldt RJ, ten Duis K, et al. Initial and residual 3D fracture displacement is predictive for patient-reported functional outcome at mid-term follow-up in surgically treated tibial plateau fractures. *J Clin Med*. 2023;12:6055.
16. Vaartjes TP, Assink N, Nijveldt RJ, Van Helden SH, Bosma E, El Mounni M, et al. Functional outcome after nonoperative management of tibial plateau fractures in skeletally mature patients: what sizes of gaps and stepoffs can be accepted? *Clin Orthop Relat Res*. 2022;480:2288–2295.
17. Assink N, Vaartjes TP, Kramer CJS, Bosma E, Nijveldt RJ, ten Brinke JG, et al. What is the patient-reported outcome and complication incidence after operative versus nonoperative treatment of minimally displaced tibial plateau fractures. *Clin Orthop Relat Res*. 2024;482:1744–1752.
18. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Int J Surg*. 2014;12:1495–1499.

19. de Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The dutch version of the knee injury and osteoarthritis outcome score: a validation study. *Health Qual Life Outcomes*. 2008;6:1–11.
20. Heir S, Nerhus TK, Røtterud JH, Løken S, Ekeland A, Engebretsen L, et al. Focal cartilage defects in the knee impair quality of life as much as severe osteoarthritis: a comparison of knee injury and osteoarthritis outcome score in 4 patient categories scheduled for knee surgery. *Am J Sports Med*. 2010;38:231–237.
21. Migliorini F, Maffulli N, Schäfer L, Simeone F, Bell A, Hofmann UK. Minimal clinically important difference (MCID), substantial clinical benefit (SCB), and patient-acceptable symptom state (PASS) in patients who have undergone total knee arthroplasty: a systematic review. *Knee Surg Relat Res*. 2024;36:3.
22. American College of Surgeons, Committee on Trauma. ATLS®: advanced trauma life support. 10th ed. Chicago: American College of Surgeons; 2018.
23. Schatzker J, McBroom R. The tibial plateau fracture. The Toronto experience 1968–1975. *Clin Orthop Relat Res*. 1979;138:94–104.
24. Naso CM, Lin S-Y, Song G, Xue H. Time trend analysis of osteoporosis prevalence among adults 50 years of age and older in the USA, 2005–2018. *Osteoporos Int*. 2025;36:547–554.
25. Clynes MA, Harvey NC, Curtis EM, Fuggle NR, Dennison EM, Cooper C. The epidemiology of osteoporosis. *Br Med Bull*. 2020;133:105–117.
26. Assink N, El MM, Kraeima J, Bosma E, Nijveldt RJ, Van Helden SH, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery results in a large multicenter cohort background: radiographic measurements of initial displacement of tibial plateau fractures and of postoperative. *J Bone Joint Surg*. 2023;105:1237–1245.
27. Haslhofer DJ, Kraml N, Winkler PW, Gotterbarm T, Klasan A. Risk for total knee arthroplasty after tibial plateau fractures: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2023;31:5145–5153.
28. Euser AM, Zoccali C, Jager KJ, Dekker FW. Cohort studies: Prospective versus retrospective. *Nephron Clin Pract*. 2009;113:c214–217.
29. Meyer VM, Benjamins S, El Moumni M, Lange JFM, Pol RA. Global overview of response rates in patient and health care professional surveys in surgery a systematic review. *Ann Surg*. 2022;275:E75–E81.

APPENDIX

Table 1 ATLS criteria for High-energy trauma mechanisms

Falls
Adults > 20 feet or 6 meters (2 stories)
Children > 10 feet or 3 meters (2-3 x height of child)
High-risk motor vehicle crash
Intrusion, including roof: >12 inches (30 cm) occupant side, >18 inches (45 cm) any side
Ejection (partial or complete) from vehicle
Death in same passenger compartment
Vehicle telemetry data consistent with high risk of injury
Auto versus pedestrian/bicyclist
Thrown, run over, or with significant (> 20 mph; 32 kph) impact
Motorcycle crash
> 20 mph

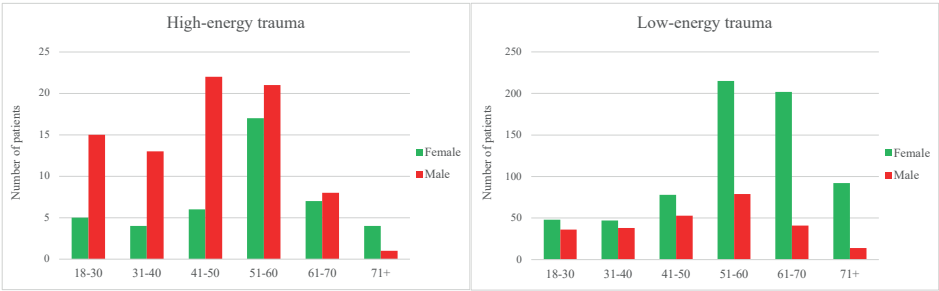


Figure 1 Age distribution of patients with tibial plateau fractures after high-energy trauma and low-energy trauma.

Chapter 3



Tibial plateau fracture morphology based on injury force mechanism is predictive for patient-reported outcome and conversion to total knee arthroplasty

Nick Assink, Thijs P. Vaartjes, Eelke Bosma,
Sven H. van Helden, Joost G. ten Brinke,
Harm Hoekstra, Frank F.A. IJpma

This chapter was published in:
European Journal of Trauma and Emergency Surgery (2024) 50:1135–1143
DOI: 10.1007/s00068-024-02447-5

ABSTRACT

Purposes The aim of this study was to assess the relationship between injury mechanism–based fracture patterns and patient-reported outcome as well as conversion rate to total knee arthroplasty (TKA) at follow-up.

Methods A multicenter cross-sectional study was performed including 1039 patients treated for a tibial plateau fracture between 2003 and 2019. At a mean follow-up of 5.8 ± 3.7 years, patients completed the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire. For all patients, the injury force mechanism was defined based on CT images. Analysis of variance (ANOVA) was used to assess the relationship between different injury mechanisms and functional recovery. Cox regression was performed to assess the association with an increased risk on conversion to TKA.

Results A total of 378 (36%) patients suffered valgus-flexion, 305 (29%) valgus-extension, 122 (12%) valgus-hyperextension, 110 (11%) varus-flexion, 58 (6%) varus-hyperextension, and 66 (6%) varus-extension injuries. ANOVA showed significant different KOOS values between injury fracture patterns in all subscales ($p < 0.01$). Varus-flexion injuries had the lowest average KOOS scores (symptoms 65; pain 67; ADL 72; sport 35; QoL 48). Varus-flexion mechanism was associated with an increased risk on a TKA (HR 1.8; $p = 0.03$) whereas valgus-extension mechanism was associated with a reduced risk on a TKA (HR 0.5; $p = 0.012$) as compared to all other mechanisms.

Conclusion Tibial plateau fracture patterns based on injury force mechanisms are associated with clinical outcome. Varus-flexion injuries have a worse prognosis in terms of patient-reported outcome and conversion rate to TKA at follow-up. Valgus-extension injuries have least risk on conversion to TKA.

INTRODUCTION

Tibial plateau fractures are one of the most challenging intra-articular fractures to treat due to complex fracture morphology [1, 2]. These fractures result from a varus or valgus load along with or without an axial load on the tibial plateau [3, 4]. Depending on the exact injury mechanism and the position of the knee, the resulting fracture patterns vary from simple split fractures to complex multi-fragmentary fractures of lateral, medial, or bicondylar types [1, 5, 6].

Both the revisited Schatzker and the three-column classification emphasized the importance of the injury mechanisms causing a tibial plateau fracture [7, 8]. Both classifications included the assessment of these mechanisms in four dimensions (varus, valgus, flexion, and extension) in order to guide surgical fixation. In addition, the hyperextension injury mechanism has been reported as a unique fracture mechanism [4, 9], which resulted in a total of six different unique tibial plateau injury mechanisms: valgus-flexion, valgus-extension, valgus-hyperextension, varus-flexion, varus-extension, and varus-hyperextension. Xie et al. recently introduced a method to assess the relationship between these different injury force mechanisms and fracture patterns [4]. This study demonstrated that those injury force mechanisms — represented by those unique fracture patterns — predict associated soft tissue injuries. Besides the descriptive nature of these mechanisms, these specific injury patterns may have predictive value on the patient's recovery over time. Even though Xie et al. identified distinct mechanism-associated 3-dimensional pattern characteristics, these well-established mechanisms — which are incorporated in the current classification mechanisms — have never been associated with functional recovery [4].

In this study, we aim to assess the relationship between the different unique tibial plateau injury mechanisms and the functional recovery at follow-up. We posed the following research questions: (1) Is the type of injury force mechanism which causes a tibial plateau fracture predictive for patient-reported functional outcome at follow-up? (2) What is the association between the type of injury force mechanism and the risk on conversion to total knee arthroplasty (TKA) at follow-up?

METHODS

A multicenter cross-sectional study was performed including all patients who have been treated for a tibial plateau fracture in five trauma centers (University Medical Center Groningen, Martini Hospital, Isala Hospital, Gelre Hospital, and KU Leuven University Hospitals) between January 2003 and December 2019. Patients were eligible for inclusion based upon the availability of a preoperative (diagnostic) CT scan of the injured knee. Patients with a follow-up of less than 1 year, age < 18 years, pathological fractures, isolated

tibial eminence fractures, or those with a complicated fracture requiring amputation of the affected leg were excluded. Patients’ demographics were retrieved from the electronic records. All patients were verified whether they were still alive according to the national population registry. All eligible patients were approached by posted mail, asked for informed consent, and asked to complete validated patient-reported outcome measures. Written informed consent was obtained from all participants.

Fracture injury mechanism assessment

Fracture injury mechanism was assessed in consensus of two independent observers. Any disagreements were solved during a consensus meeting with a third observer. Assessments were performed on the 2D CT slices using the Mimics Medical software package (Version 23.0, Materialise, Leuven, Belgium) according to the method described by Xie et al. [4]. Additionally, the injury mechanism was verified on a 3D reconstruction of the fracture. This reconstruction was obtained following a segmentation process in which a preset bone threshold (Hounsfield unit ≥ 226) was used combined with the “region growing” function in order to remove the femur bone. Figure 1 illustrates the fracture injury mechanism assessment.

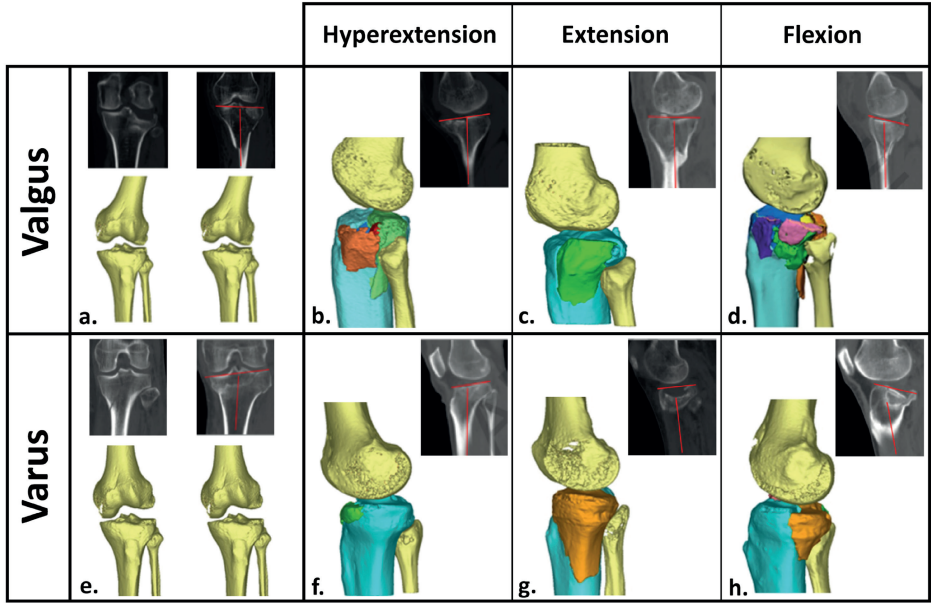


Figure 1 Fracture injury mechanism assessment. Fractures limiting to the lateral side or with an increased medial proximal tibial angle (MPTA) are considered caused by valgus impact (a) and fractures limited to the medial side or with decreased MPTA as varus impact (e). Fractures with a decreased tibial slope are considered as hyperextension (b, f), normal tibial slope as extension (c, g), and increased tibial slope as flexion (d, h).

Patient-reported outcomes

All eligible patients were approached by posted mail and asked to complete the standardized Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire [10]. Additionally, patients were asked whether they received a total knee prosthesis. The KOOS is a validated questionnaire consisting 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 was calculated for each subscale. Scores of the subscales are calculated by summing up the individual items (e.g., questions) and transforming scores on a range from 0 to 100, with higher scores indicating better function. In addition, the patients were also asked whether they underwent conversion to TKA.

Statistical analysis

IBM SPSS software, version 23.0 for Windows (IBM Corporation, Chicago, IL, USA), was used for statistical analysis. Continuous variables were presented as mean and standard deviation (SD) for normally distributed data and median and interquartile range (IQR) if not normally distributed. Descriptive statistics were used to describe the study population. The study population was divided into groups based on the injury mechanism, after which analysis of variance (ANOVA) was used to assess differences between the groups in terms of functional outcome. Cox regression was performed to assess the risk on conversion to a TKA. In this analysis, we corrected for other factors (age, sex, smoking, and BMI) which are potential confounders for the risk of conversion to a TKA. A p-value of less than 0.05 was considered statistically significant.

Ethical approval

The institutional review board of all centers approved the study procedures, and the research was performed in accordance with the relevant guidelines and regulations. This study is reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline [11].

Source of funding

There was no external funding source for this study.

RESULTS

A total of 2331 patients were treated for a tibial plateau fracture between 2003 and 2019, of which 61 had and isolated tibial eminence avulsions (e.g., cruciate ligament injuries), 115 were aged < 18 years, 191 had died at follow-up, 82 had co-existing conditions complicating outcome measurement (e.g., Parkinson, paralysis), 4 had an amputation, 13 had no knowledge of the Dutch language, and 53 had an unknown address or were lost at follow-up, leaving 1750 patients eligible for follow-up analysis. All patients were approached by posted mail, from which 1039 responded (response rate 59%) at a mean follow-up of 5.8 ± 3.7 years. The mean age was 53 ± 15 years and 32% (329) of patients were male. A total of 728 (70%) patients were treated operatively by using plate and/or screw osteosynthesis. Eventually, 111 (11%) patients underwent conversion to TKA during follow-up. Non-response analysis demonstrated that non-responders were slightly younger (51 ± 18 vs. 53 ± 15 , $p = 0.001$), less often female (59% vs. 68%, $p = 0.001$), and less often treated surgically (56% vs. 70%, $p = 0.001$) in comparison with responders.

Valgus mechanisms (805/1039, 77%) occurred more frequently than varus (234/1039, 23%) mechanisms. A total of 378 (36%) patients were classified as valgus-flexion, 305 (29%) as valgus-extension, 122 (12%) as valgus-hyperextension, 110 (11%) as varus-flexion, 58 (6%) as varus-hyperextension, and 66 (6%) as varus-extension. Table 1 describes patients demographics for each trauma mechanism.

Table 1 Patient characteristics

	Valgus-flexion	Valgus-extension	Valgus-hyperextension	Varus-flexion	Varus-extension	Varus-hyperextension
Number of patients	378 (36%)	305 (29%)	122 (12%)	110 (11%)	58 (6%)	66 (6%)
Age (yrs)	54 ± 14	54 ± 15	51 ± 15	53 ± 17	55 ± 16	46 ± 14
Male	98 (65%)	100 (33%)	46 (38%)	33 (32%)	22 (38%)	30 (45%)
BMI (kg/m ²)	26.2 ± 4.8	26.3 ± 4.7	25.4 ± 4.0	26.5 ± 4.5	26.6 ± 4.2	27.4 ± 5.5
Smoking	73 (19%)	68 (22%)	26 (21%)	22 (20%)	8 (14%)	13 (20%)
Diabetes	28 (7%)	28 (9%)	12 (10%)	6 (6%)	7 (12%)	3 (5%)
AO/OTA classification						
B1	20 (5%)	48 (16%)	5 (4%)	10 (9%)	17 (30%)	26 (39%)
B2	109 (29%)	94 (31%)	22 (18%)	8 (7%)	9 (16%)	5 (8%)
B3	167 (44%)	148 (48%)	80 (66%)	38 (34%)	19 (32%)	15 (22%)
C1	12 (3%)	1 (0%)	6 (5%)	4 (4%)	6 (10%)	7 (11%)
C2	2 (1%)	3 (1%)	3 (2%)	2 (2%)	0 (0%)	6 (9%)
C3	68 (18%)	11 (4%)	6 (5%)	48 (44%)	7 (12%)	7 (11%)
Treatment						
Non-operative	117 (31%)	94 (31%)	14 (11%)	25 (22%)	32 (55%)	29 (44%)
Screw osteosynthesis	38 (10%)	65 (21%)	13 (11%)	2 (2%)	3 (5%)	8 (12%)
Plate osteosynthesis	223 (59%)	146 (48%)	95 (78%)	83 (76%)	23 (40%)	29 (44%)
Conversion to TKA	46 (12%)	22 (7%)	11 (9%)	20 (18%)	8 (14%)	4 (6%)
Follow-up (yrs)	5.6 ± 3.6	6.1 ± 3.9	5.6 ± 3.6	5.3 ± 3.3	5.9 ± 3.9	6.6 ± 4.2

Patient-reported outcomes

The average KOOS score per KOOS subscale for each trauma mechanism is depicted in Figure 2. ANOVA analysis showed significant different KOOS values between injury mechanism groups in terms of all KOOS subscales ($p < 0.001$, Appendix). Tukey's post hoc analysis showed that patients with a fracture caused by a varus-flexion injury had significantly worse KOOS subscales regarding symptoms ($p \leq 0.002$), pain ($p \leq 0.007$), sport ($p \leq 0.01$), and QoL ($p \leq 0.026$) as compared to all other mechanisms. In terms of ADL, varus-flexion was significantly worse as compared to all other subscales with exemption of valgus-hyperextension ($p = 0.012$).

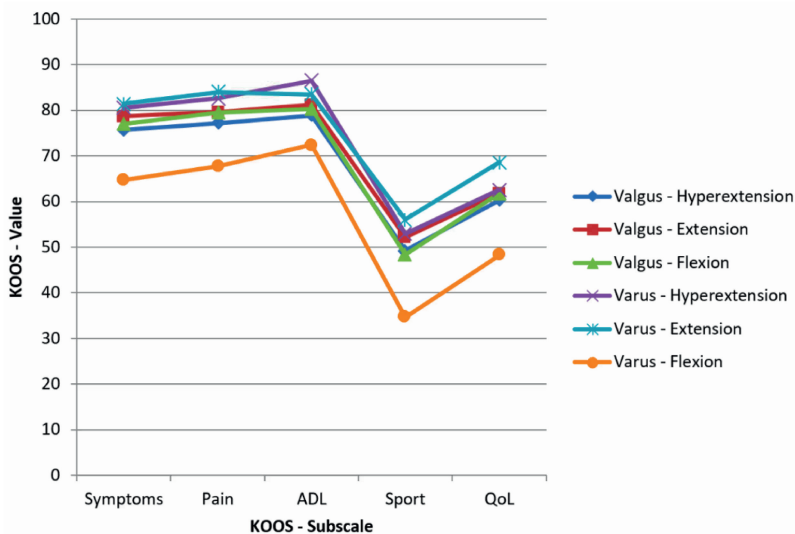


Figure 2 The average KOOS values for each of the KOOS subscales, representing functional outcome, are displayed for 944 patients with a tibial plateau fracture divided into six subgroups based on the injury fracture mechanism.

Conversion to TKA

Kaplan–Meier survival analysis shows knee survival free of conversion to TKA in non-surgical treated patients of 97% at 2 years and 94% at 10 years. In surgically treated patients, 2- and 10-year knee survival was 93% and 82%, respectively. When stratifying groups based on the injury force mechanism, the 2-year knee survival (no conversion to TKA) was 92% for valgus-flexion, 96% for valgus-extension, and 96% for valgus-hyperextension. For varus-flexion, extension, and hyperextension injuries, the 2-year knee survival was 92%, 90%, and 95%, respectively. The 10-year knee survival was 84% for valgus-flexion, 91% for valgus-extension, 88% for valgus-hyperextension, 71% for varus-flexion, 86% for varus-extension, and 92% for varus-hyperextension (Figs. 3 and 4).

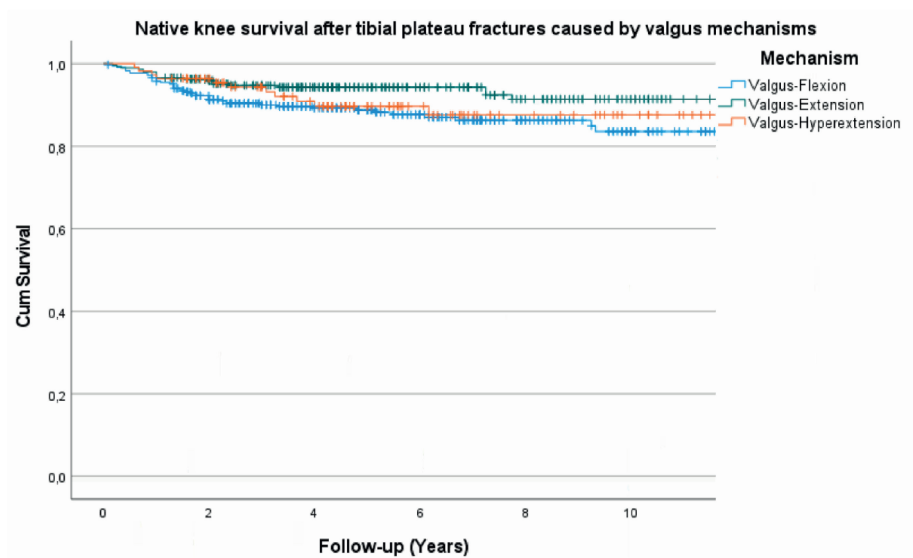


Figure 3 Native knee survival free from conversion to total knee arthroplasty stratified by valgus injury mechanisms (log rank, $p = 0.010$).

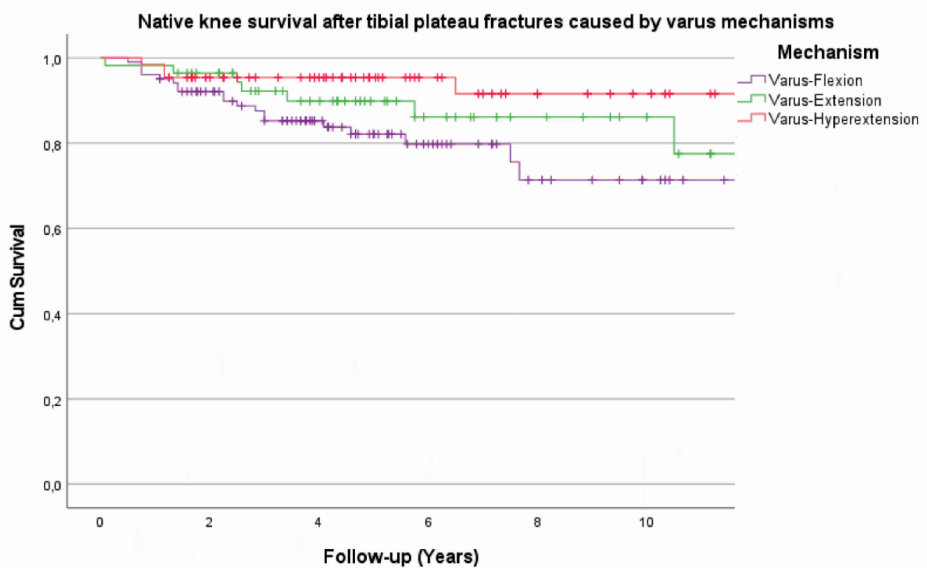


Figure 4 Native knee survival free from conversion to total knee arthroplasty stratified by varus injury mechanisms (log rank, $p = 0.075$).

Univariate analysis shows that the valgus-extension mechanism was associated with a reduced risk on a TKA (HR 0.6; $p = 0.028$), whereas the varus-flexion mechanism was associated with an increased risk on a TKA (HR 2.0; $p = 0.003$) as compared to the other mechanisms. After correction for age, sex, smoking, diabetes, and BMI, multivariate analysis showed similar results with valgus-extension mechanism associated with a reduced risk (adj HR 0.5; $p = 0.012$) and varus-flexion with increased risk on a TKA (adj HR 1.8; $p = 0.030$) (Table 2).

Table 2 Multivariate analysis of the association of injury force mechanisms with the conversion to TKA

Injury Mechanism*	Unadjusted hazard ratio (95% CI)	P-value	Adjusted hazard ratio† (95% CI)	P-value
Valgus-flexion	1.2 (0.8 – 1.8)	0.333	1.4 (0.9 – 2.1)	0.105
Valgus-extension	0.6 (0.3 – 0.9)	0.028*	0.5 (0.3 – 0.9)	0.012*
Valgus-hyperextension	0.8 (0.4 – 1.5)	0.777	0.9 (0.5 – 1.7)	0.750
Varus-flexion	2.0 (1.3 – 3.3)	0.003*	1.8 (1.1– 3.1)	0.030*
Varus-extension	1.3 (0.7 – 2.8)	0.428	0.8 (0.3 – 2.0)	0.672
Varus-hyperextension	0.6 (0.2 – 1.5)	0.246	0.9 (0.3 – 2.5)	0.847

*The patients who had a different injury force mechanism as the injury mechanism of interest served as the reference group.

†Adjusted for age, sex, smoking, diabetes and BMI.

*Significant

Why injury force mechanisms affect clinical outcome

A subanalysis was performed to assess the role of revision surgeries as potential explanation for the identified variations in clinical outcomes among different injury mechanisms. Varus-flexion injuries are associated with substantial rates of revision surgery as a result of fracture-related infections (13%), residual displacement (8%), or meniscal/ligamentous repairs (7%) as compared to the other injury mechanisms. Table 3 presents rates of revision surgery pertaining to different injury mechanisms in tibial plateau fracture surgery.

Table 3 Revision surgery associated with different injury force mechanisms in tibial plateau fracture surgery

	Valgus-flexion	Valgus-extension	Valgus-hyperextension	Varus-flexion	Varus-extension	Varus-hyperextension
Number of patients	378 (36%)	305 (29%)	122 (12%)	110 (11%)	58 (6%)	66 (6%)
Operative treatment	261 (67%)	211 (69%)	108 (89%)	85 (77%)	26 (45%)	37 (56%)
Revision surgery						
Reoperation for fracture-related infection*	15 (6%)	4 (2%)	1 (1%)	11 (13%)	0 (0%)	0 (0%)
Revision surgery for residual displacement	7 (2%)	2 (1%)	3 (3%)	9 (8%)	0 (0%)	0 (0%)
Reoperation for meniscal or ligamentous repair	8 (2%)	4 (1%)	1 (1%)	8 (7%)	1 (2%)	4 (6%)

*As percentage of patients treated operatively.

DISCUSSION

Tibial plateau fracture morphologies based on six different injury force mechanisms, each with its own associated distinct fracture characteristics and soft tissue involvement, have been introduced [4]. To our knowledge, this is the first large multicenter study which relates these specific injury mechanisms to patients' functional recovery in terms of patient-reported outcome and conversion to TKA. Our results show that especially fractures caused by a varus-flexion force have worse prognosis as compared to the other mechanisms regarding both patient-reported outcome and risk on conversion to TKA. On the contrary, fractures caused by a valgus-extension mechanism are associated with reduced risk on a TKA as compared to the other injury mechanisms.

In the recently updated versions of the Schatzker and three-column classification methods, more focus is directed on mechanisms of injury which result in different fracture patterns [7, 8]. In these classifications, identifying the position of the knee (flexion/extension) and the deforming force (varus/valgus) guides the surgeon in the preoperative planning and surgical stabilization of the fracture [7, 8]. The results of our study add knowledge regarding the consequences of these mechanisms on patients' prognosis. Therefore, increasing knowledge about the injury mechanism and the corresponding fracture morphology could aid in providing the patient information regarding his or her expected functional recovery.

The results of this study indicate that especially the varus-flexion mechanism results in worse patient-reported outcomes as compared to other mechanisms of injury. These

fractures are caused by a varus force, with the knee in a flexion position. Therefore, these fractures usually involve the medial and posterior part of the tibial plateau. Recently, van den Berg et al. showed that especially fractures with posterior involvement as well as sagittal malalignment were associated with poor outcomes [12, 13]. It is believed that fractures of the medial plateau usually require more force and are therefore often not only limited to the medial compartment. This is confirmed by Xie et al. who describe that varus-flexion fractures are associated with posterolateral articular comminution and anterior cruciate ligament avulsion [4]. The combination of a medial fracture with posterolateral comminution and associated ligamentous damage in fractures caused by a varus-flexion trauma might explain the worse clinical outcome. This is supported by our subanalysis which showed that patients who had a fracture caused by a varus-flexion injury required more often reoperations for meniscal or ligamentous repair, residual displacement, and fracture-related infections as compared to other mechanisms of injury. Therefore, fractures caused by a varus-flexion trauma might especially benefit from an extensive 3D surgical planning which could potentially improve surgical outcomes [14]. Moreover, valgus traumas are associated with medial collateral ligament (MCL) sprains which are relatively forgiving, whereas varus traumas are associated with (postero)lateral ligamentous injuries which are often underestimated and could affect outcome negatively [15].

Tibial plateau fractures could result in severe post-traumatic osteoarthritis or ligamentous instability needing eventually conversion to total knee arthroplasty. This study shows that patients with a fracture caused by a flexion injury mechanism are more likely to receive a TKA as compared to the other injury mechanisms. Varus-flexion mechanisms appear to be almost two times more likely to undergo conversion to a TKA compared to the other injury mechanisms (adj HR 1.8, 95% CI, 1.1–3.1). Also, the valgus-flexion mechanism showed a trend towards an increased risk of conversion to TKA (adj HR 1.4, 95% CI, 0.9–2.1). This increased risk in fractures caused by a flexion force could be explained by the involvement of the posterior part of the tibial plateau as well as the relatively high incidence of C3 fractures. Our findings are in line with recent research, indicating that inadequate alignment of the sagittal tibial axis is strongly associated with conversion to TKA [16]. On the contrary, the valgus-extension mechanism was associated with a reduced risk on conversion to a TKA compared to other groups (adj HR 0.5, 95% CI, 0.3–0.9). This reduced risk could be explained by the fact that these fractures are mainly limited to the lateral compartment of the tibial plateau and usually consist of solely a central depression and/or pure split fragment [4].

This study has a few limitations which need to be addressed. First, we acknowledge that selection bias is inherent to a cross-sectional study design caused by loss to follow-up and non-response. Non-response analysis demonstrates that non-responders were on average 2 years younger and more often female. Yet, the small difference in age and gender is not expected to affect the generalizability of our results. Interestingly, when

comparing our patient group with the patients described by Xie et al., our population has a higher proportion of females and less fractures caused by a varus force. This may be due to demographic and cultural differences between western Europe and China. Second, our research solely focusses on the relationship between the injury force mechanism and patient-reported outcome as well as conversion to TKA. For future research, a more detailed comparison between injury force mechanisms regarding both the fractures' location and initial displacement of tibial plateau fractures and of postoperative reduction based on two-dimensional CT slices and even more advanced three-dimensional imaging techniques would be helpful to further elucidate factors that affect prognosis. [17, 18]. Third, our subanalysis demonstrated some differences in reoperations due to soft tissue injuries between injury mechanisms. Although, the true level of concomitant ligamental and meniscal damage presented at the time of injury is still matter of debate. A recent review indicated that at least one ligamental or meniscal lesion is present in 93% of patients with tibial plateau fractures [19]. This again emphasizes the importance of a full assessment of concomitant soft tissue injuries in especially tibial plateau fractures with posterolateral involvement caused by varus-flexion mechanisms [20]. A preoperative MRI could therefore be useful in selected cases and contribute to decision-making regarding treatment strategies. In addition, a preoperative MRI could help to quantify the condition of the cartilage and the extent of preexisting osteoarthritis. We envision for the future to tibial plateau fracture management a three-dimensional diagnostic workup in which fracture characteristics and a full soft tissue assessment will be combined [17].

In conclusion, this large multicenter study demonstrated that tibial plateau fracture morphology based on injury force mechanism is predictive for patient-reported outcome and conversion to total knee arthroplasty. This study showed that in particular fractures caused by a varus-flexion force have a worse prognosis, whereas fractures caused by a valgus-extension force have less risk on conversion to a TKA. These findings can help in patient counselling, identifying patients who might benefit from advanced preoperative workup (i.e., MRI/3D surgical planning), and estimating prognosis in the management of complex tibial plateau fractures.

REFERENCES

1. Molenaars RJ, Mellema JJ, Doornberg JN, Kloen P. Tibial plateau fracture characteristics: computed tomography mapping of lateral, medial, and bicondylar fractures. *J Bone Joint Surg Am.* 2015;97;1512–20.
2. Barei DP, O'Mara TJ, Taitsman LA, Dunbar RP, Nork SE. Frequency and fracture morphology of the posteromedial fragment in bicondylar tibial plateau fracture patterns. *J Orthop Trauma.* 2008;22:176–82.
3. Zhang BB, Sun H, Zhan Y, He QF, Zhu Y, Wang YK, et al. Reliability and repeatability of tibial plateau fracture assessment with an injury mechanism-based concept. *Bone Joint Res.* 2019;8:357–366.
4. Xie X, Zhan Y, Wang Y, Lucas JF, Zhang Y, Luo C. Comparative analysis of mechanism-associated 3-dimensional tibial plateau fracture patterns. *J Bone Joint Surg Am.* 2020;102:410–418.
5. Yao X, Zhou K, Lv B, Wang L, Xie J, Fu X, et al. 3D mapping and classification of tibial plateau fractures. *Bone Joint Res.* 2020;9:258–267.
6. Hua K, Jiang X, Zha Y, Chen C, Zhang B, Mao Y. Retrospective analysis of 514 cases of tibial plateau fractures based on morphology and injury mechanism. *J Orthop Surg Res.* 2019;14:1–10.
7. Kfuri M, Schatzker J. Revisiting the Schatzker classification of tibial plateau fractures. *Injury.* 2018;49:2252–2263.
8. Wang Y, Luo C, Zhu Y, Zhai Q, Zhan Y, Qiu W, et al. Updated three-column concept in surgical treatment for tibial plateau fractures - a prospective cohort study of 287 patients. *Injury.* 2016;47:1488–1496.
9. Gonzalez LJ, Lott A, Konda S, Egol KA. The hyperextension tibial plateau fracture pattern: a predictor of poor outcome. *J Orthop Trauma.* 2017;31:e369–e374.
10. De GIB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of the Knee Injury and Osteoarthritis Outcome Score: a validation study. *Health Qual Life Outcomes.* 2008;6:1–11.
11. Von EE, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Bull World Health Organ.* 2007;85:867–872.
12. Van Den BJ, Reul M, Nunes Cardozo M, Starovoyt A, Geusens E, Nijs S, et al. Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures. *Int Orthop.* 2017;41:1865–1873.
13. Van den Berg J, De Boer AS, Assink N, Haveman R, Reul M, Link BC, et al. Trauma mechanism and patient reported outcome in tibial plateau fractures with posterior involvement. *Knee.* 2021;30:41–50.
14. Assink N, Reininga IHF, Duis K ten, Doornberg JN, Hoekstra H, Kraeima J, et al. Does 3D-assisted surgery of tibial plateau fractures improve surgical and patient outcome? A systematic review of 1074 patients. *Eur J Trauma Emergency Surg.* 2022;48:1737–1749.
15. Van den Berg JD, Quintens L, Zhan Y, Hoekstra H. Why address posterior tibial plateau fractures? *Injury.* 2020;51:2779–2785.
16. Assink N, Moumni M El, Kraeima J, Bosma E, Nijveldt RJ, Helden SH van, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery: results in a large multicenter cohort. *J Bone Joint Surg Am.* 2023;105:1237–1245.

17. Assink N, Kraeima J, Meesters AML, Mounni M El, Bosma E, Nijveldt RJ, et al. 3D assessment of initial fracture displacement of tibial plateau fractures is predictive for risk on conversion to total knee arthroplasty at long-term follow-up. *Eur J Trauma Emerg Surg.* 2022;49:867–874.
18. Assink N, Kraeima J, Slump CH, ten Duis K, de Vries JPPM, Meesters AML, et al. Quantitative 3D measurements of tibial plateau fractures. *Sci Rep.* 2019;9:14395.
19. Thürig G, Korthaus A, Frosch K-H, Krause M. The value of magnetic resonance imaging in the preoperative diagnosis of tibial plateau fractures: a systematic literature review. *Eur J Trauma Emerg Surg.* 2022; 49; 661–679.
20. Hoekstra H, Krause M. The posterolateral dilemma. *Knee.* 2023;42:413–414.

APPENDIX

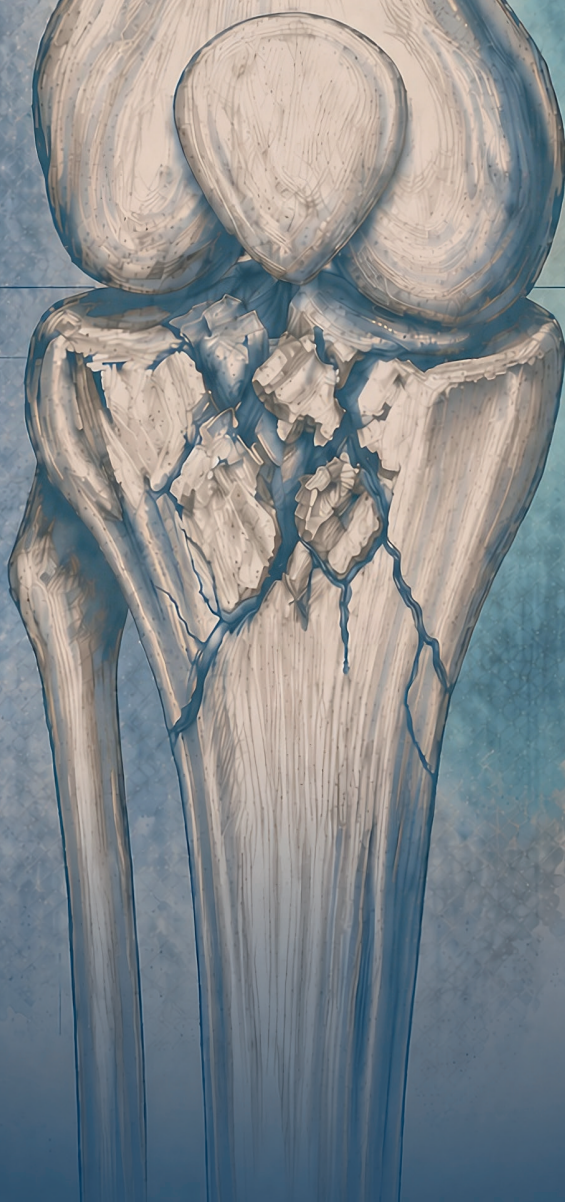
Table 1 Injury mechanisms correlated with patient-reported outcome

	Valgus- flexion	Valgus- extension	Valgus- hyperextension	Varus- flexion	Varus- extension	Varus- hyperextension	P-value
No. of fractures	378	305	122	110	58	66	
KOOS	76.8 ± 21.5	78.2 ± 20.7	75.7 ± 22.5	65.0 ± 21.9	80.9 ± 22.1	80.8 ± 18.0	< 0.001
symptoms							
KOOS pain	78.9 ± 21.9	79.1 ± 21.8	77.1 ± 22.5	67.0 ± 22.5	83.8 ± 19.4	82.9 ± 19.7	< 0.001
KOOS ADL	80.0 ± 21.9	80.8 ± 21.2	79.1 ± 22.2	71.7 ± 22.5	83.0 ± 22.8	86.7 ± 16.8	< 0.001
KOOS sport	48.4 ± 35.4	51.4 ± 34.	50.7 ± 36.5	34.6 ± 29.1	54.5 ± 38.3	53.7 ± 32.8	< 0.001
KOOS	61.2 ± 28.9	60.9 ± 28.8	60.3 ± 29.5	47.8 ± 24.7	68.2 ± 28.1	63.2 ± 26.1	< 0.001
quality of life							

*Significant

TIBIAL PLATEAU
FRACTURE

ANTERIOR VIEW



PART II

How are they treated

Chapter 4



Functional Outcome After Nonoperative Management of Tibial Plateau Fractures in Skeletally Mature Patients: What Sizes of Gaps and Stepoffs Can be Accepted?

Thijs P. Vaartjes, Nick Assink, Robert J. Nijveldt,
Sven H. van Helden, Eelke Bosma, Mostafa El Mounni,
Kaj ten Duis, Mike Hogervorst, Job N. Doornberg,
Jean-Paul P.M. de Vries, Harm Hoekstra, Frank F.A. IJpma

This chapter was published in:
Clinical Orthopaedics and Related Research (2022) 480:2288-2295
DOI: 10.1097/CORR.0000000000002266

ABSTRACT

Background Gap and stepoff measurements provide information about fracture displacement and are used for clinical decision-making when choosing either operative or nonoperative management of tibial plateau fractures. However, there is no consensus about the maximum size of gaps and stepoffs on CT images and their relation to functional outcome in skeletally mature patients with tibial plateau fractures who were treated without surgery. Because this is important for patient counseling regarding treatment and prognosis, it is critical to identify the limits of gaps and stepoffs that are well tolerated.

Questions/purposes (1) In patients treated nonoperatively for tibial plateau fractures, what is the association between initial fracture displacement, as measured by gaps and stepoffs at the articular surface on a CT image, and functional outcome? (2) What is the survivorship of the native joint, free from conversion to a total knee prosthesis, among patients with tibial plateau fractures who were treated without surgery?

Methods A multicenter cross-sectional study was performed in all patients who were treated nonoperatively for a tibial plateau fracture between 2003 and 2018 in four trauma centers. All patients had a diagnostic CT scan, and a gap and/or stepoff more than 2 mm was an indication for recommending surgery. Some patients with gaps and/or stepoffs exceeding 2 mm might not have had surgery based on shared decision-making. Between 2003 and 2018, 530 patients were treated nonoperatively for tibial plateau fractures, of which 45 had died at follow-up, 30 were younger than 18 years at the time of injury, and 10 had isolated tibial eminence avulsions, leaving 445 patients for follow-up analysis. All patients were asked to complete the validated Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire consisting of five subscales: symptoms, pain, activities of daily living (ADL), function in sports and recreation, and knee-related quality of life (QOL). The score for each subscale ranged from 0 to 100, with higher scores indicating better function. A total of 46% (203 of 445) of patients participated at a mean follow-up of 6 ± 3 years since injury. All knee radiographs and CT images were reassessed, fractures were classified, and gap and stepoff measurements were taken. Nonresponders did not differ much from responders in terms of age (53 ± 16 years versus 54 ± 20 years; $p = 0.89$), gender (70% [142 of 203] women versus 59% [142 of 242] women; $p = 0.01$), fracture classifications (Schatzker types and three-column concept), gaps (2.1 ± 1.3 mm versus 1.7 ± 1.6 mm; $p = 0.02$), and stepoffs (2.1 ± 2.2 mm versus 1.9 ± 1.7 mm; $p = 0.13$). In our study population, the mean gap was 2.1 ± 1.3 mm and stepoff was 2.1 ± 2.2 mm. The participating patients divided into groups with increasing fracture displacement based on gap and/or stepoff (< 2 mm, 2 to 4 mm, or > 4 mm), as measured on CT images. ANOVA was used to assess whether an increase in the initial fracture displacement was associated with poorer functional outcome. We estimated the survivorship of the knee free from conversion to total knee prosthesis at a mean follow-up of 5 years using a Kaplan-Meier survivorship estimator.

Results KOOS scores in patients with a less than 2 mm, 2 to 4 mm, or greater than 4 mm gap did not differ (symptoms: 83 versus 83 versus 82; $p = 0.98$, pain: 85 versus 83 versus 86; $p = 0.69$, ADL: 87 versus 84 versus 89; $p = 0.44$, sport: 65 versus 64 versus 66; $p = 0.95$, QOL: 70 versus 71 versus 74; $p = 0.85$). The KOOS scores in patients with a less than 2 mm, 2 to 4 mm, or greater than 4 mm stepoff did not differ (symptoms: 84 versus 83 versus 77; $p = 0.32$, pain: 85 versus 85 versus 81; $p = 0.66$, ADL: 86 versus 87 versus 82; $p = 0.54$, sport: 65 versus 68 versus 56; $p = 0.43$, QOL: 71 versus 73 versus 61; $p = 0.19$). Survivorship of the knee free from conversion to total knee prosthesis at mean follow-up of 5 years was 97% (95% CI 94% to 99%).

Conclusion Patients with minimally displaced tibial plateau fractures who opt for nonoperative fracture treatment should be told that fracture gaps or stepoffs up to 4 mm, as measured on CT images, could result in good functional outcome. Therefore, the arbitrary 2-mm limit of gaps and stepoffs for tibial plateau fractures could be revisited. The survivorship of the native knee free from conversion to a total knee prosthesis was high. Large prospective cohort studies with high response rates are needed to learn more about the relationship between the degree of fracture displacement and functional recovery after tibial plateau fractures.

INTRODUCTION

The World Health Organization recommends taking 10,000 steps a day to stay healthy [22], which equates to approximately 3 million steps per person each year. A tibial plateau fracture may have a major impact on a patient's mobility, social activities, and ability to work. Adequate treatment is crucial to minimize the risks of progressive posttraumatic arthritis and patient disability [1, 5, 10, 11]. Assessment of fracture displacement is essential to choose the best treatment strategy for tibial plateau fractures [8]. Gap and stepoff measurements, which provide information about fracture displacement, are used for clinical decision-making when choosing between operative or nonoperative treatment. Nonoperative management usually consists of a knee brace or long-leg cast for several weeks and is considered a good option for the treatment of minimally displaced tibial plateau fractures [5, 10, 11].

A frequently reported indication for nonoperative treatment of tibial plateau fractures includes minimal displacement with an articular fracture gap and/or stepoff of less than 2 mm [12, 13]. However, in a review of previous studies, Giannoudis et al. [4] reported that articular gaps and stepoffs up to 10 mm are well tolerated and could be accepted for nonoperative treatment. However, we are not aware of any evidence regarding fracture displacement and the functional outcome after nonoperative treatment of tibial plateau fractures. Most studies of tibial plateau fracture treatment are focused on functional outcomes after surgery [7, 19, 21]. Moreover, few studies have primarily focused on the correlation between initial fracture displacement and functional outcome [7, 15, 16, 18]. Additionally, several studies [4] have used standard radiographs to assess fracture displacement, whereas over time, clinical decision-making has become increasingly based on CT images. CT images have been shown to increase the accuracy of assessing fracture displacement [12]. There seems to be no consensus on the impact of minimal fracture displacement on functional outcome. Because the degree of fracture displacement is important for patient counseling regarding the indications for surgery and prognosis, it is crucial to assess what sizes of gaps and stepoffs could be accepted for the nonoperative treatment of tibial plateau fractures.

We therefore asked: (1) In patients treated nonoperatively for tibial plateau fractures, what is the association between initial fracture displacement, as measured by gaps and stepoffs at the articular surface on a CT image, and functional outcome? (2) What is the survivorship of the native joint, free from conversion to total knee prosthesis, among patients with tibial plateau fractures who were treated without surgery?

PATIENTS AND METHODS

Study Design and Setting

A multicenter cross-sectional study was performed in patients who were treated nonoperatively for a tibial plateau fracture between January 2003 and December 2018 at the University Medical Center Groningen (The Netherlands), Isala (The Netherlands), University Hospitals Leuven (Belgium), and Martini hospital (The Netherlands). These include, respectively, three Level 1 trauma centers and one Level 2 trauma center.

Participants

Patients with a preoperative (diagnostic) CT image and follow-up of at least 1 year were eligible for inclusion. A gap and/or stepoff of more than 2 mm, as measured on a CT scan, was an indication for recommending surgery. Some patients with gaps and/or stepoffs exceeding 2 mm might not have had surgery due to shared decision-making. The exclusion criteria were age younger than 18 years at the time of injury, pathologic fractures, isolated tibial eminence avulsions (such as cruciate ligament injuries), and patients who were deceased at the time of follow-up. Between 2003 and 2018, 530 patients were treated nonoperatively for a tibial plateau fracture, of which 45 had died at follow-up, 30 were younger than 18 years at the time of injury, and 10 had isolated tibial eminence avulsions, leaving 445 patients for follow-up analysis. All eligible patients were approached by posted mail and asked to provide informed consent and complete validated patient-reported outcome measures. A total of 46% (203 of 445) of the patients participated. The mean age at the time of injury was 53 ± 16 years, 70% (142 of 203) of patients were women, and the mean follow-up duration after injury was 6 ± 3 years (Table 1).

Table 1 Patient characteristics (n = 203)

Parameter	Value
Age (years)	53 ± 16
Woman	70 (142)
Smoking	13 (26)
BMI in kg/m ²	27 ± 4.6
Schatzker classification	
Type I	18 (37)
Type II	27 (54)
Type III	39 (80)
Type IV	12 (25)
Type V	2 (4)
Type VI	1 (3)
Three Column classification	
One Column	58 (118)
Two Columns	35 (71)
Three Columns	7 (14)
Gap (mm)	2.1 ± 1.3
Stepoff (mm)	2.1 ± 1.2
Conversion to total knee prosthesis	3 (7)
Follow-up (years)	6 ± 3

Data presented as mean ± SD or % (n).

CT-based Gap and Stepoff Measurements

All knee radiographs and CT images, which were taken within 2 weeks after the patient's injury, were reassessed through consensus by two observers (NA, FFAIJ) with experience in tibial plateau fracture management. All tibial plateau fractures were classified according to the Schatzker classification [14] and three-column classification [20]. Gap and stepoff measurements were taken using CT images. Gap was defined as separation of fracture fragments along the articular surface. Stepoff was characterized as separation of fracture fragments perpendicular to the articular surface [1]. For each patient, the maximum value of the gap or stepoff on any of the axial, coronal, or sagittal CT slices was measured (Fig. 1). Measurements were performed with a digital measurement tool in the Mimics Medical software package (Version 21.0, Materialise). The relationship between the measured initial fracture displacement (gaps and stepoffs) and functional outcome was assessed.

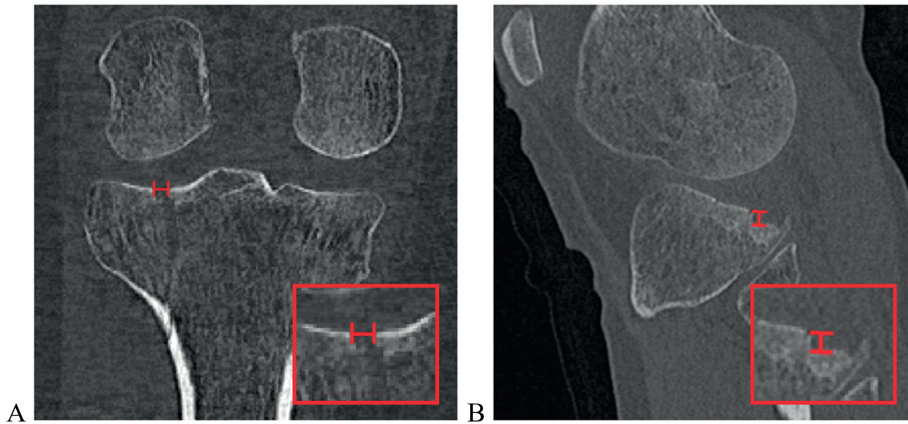


Figure 1 A-B The measurements of the fracture displacement are displayed in the (A) coronal (gap 3.7 mm) and (B) sagittal (stepoff 3.8 mm) views.

Patient-reported Outcomes

All eligible patients were approached by posted mail and asked to complete the standardized Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire [2]. Additionally, patients were asked whether they received a total knee prosthesis. The KOOS is a validated questionnaire consisting of five subscales: symptoms, pain, activities of daily living (ADL), function in sports and recreation, and knee-related quality of life (QOL). A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) was calculated for each subscale. Scores of the subscales are calculated by adding the individual items (questions) and transforming scores to a range from 0 to 100, with higher scores indicating better function. The minimum clinically important differences (MCID) for five subscales of the KOOS are: symptoms = 11, pain = 17, ADL = 18, sport = 13, and QOL = 16 [9].

Data Sources

Baseline characteristics of the participants were retrieved from the patients' electronic records. The scores of the KOOS questionnaire were calculated from the patient survey of the responding patients.

Primary and Secondary Study Outcomes

Our primary study goal was to assess whether an increased gap and/or stepoff is associated with poorer functional outcome after nonoperative management of tibial plateau fractures. To achieve this, we reassessed CT scans for initial fracture displacement (gaps and/or

stepoffs) and related these measurements to a validated patient-reported outcome (KOOS questionnaire) at follow-up.

Our secondary study goal was to assess the survivorship of the knee free from conversion to total knee prosthesis after nonoperative management of tibial plateau fractures. To achieve this, we asked all patients whether they had conversion to total knee prosthesis at follow-up and determined the survivorship of the native knee among patients with tibial plateau fractures who were treated without surgery. Two authors (NA, FFAIJ) reassessed radiographs taken at the time of injury and at follow-up for the presence of osteoarthritis according to the Kellgren-Lawrence classification [6]. Conversion to a total knee prosthesis was considered a worse outcome (or endpoint), and therefore, KOOS scores obtained after placement of the prosthesis could not be included in the analysis.

Ethical Approval

The institutional review boards of all participating centers approved the study procedures, and the study was performed in accordance with the relevant guidelines and regulations.

Statistical Analysis

We used IBM SPSS software, version 23.0 for Windows (IBM Corp), for statistical analyses. Continuous variables are presented as the mean and SD for normally distributed data and median and IQR for nonnormally distributed data. Descriptive statistics were used to describe the study population. The study population was divided into groups based on the size of the gap or stepoff (< 2 mm, 2 to 4 mm, and > 4 mm), and ANOVA was used to assess differences between the groups in terms of functional outcome. Post hoc sample size calculation showed that at least 16 patients would be needed in each group to detect an MCID of 10 points in KOOS score by using 80% statistical power, $\alpha = 0.05$, and an SD of 10. We used linear regression to analyze the relationship between the gap or stepoff and KOOS score. The model was adjusted for potential confounders, including gender, age at the time of injury, BMI, and the number of columns involved (Supplementary Digital Content 1; <https://links.lww.com/CORR/A828>). We estimated the survivorship of the knee free from conversion to total knee prosthesis at a mean follow-up of 5 years using a Kaplan-Meier survivorship estimator. The significance level was set at $p < 0.05$.

Analysis of Nonparticipants

For the nonresponse analysis, we used an independent-samples t-test for continuous variables and a chi-square test for noncontinuous variables. The nonresponse analysis showed no differences in age between responders and nonresponders (53 ± 16 years versus 54 ± 20 years; $p = 0.89$). Women responded more often (70% [142 of 203] versus 59% [142 of 242]; $p = 0.01$). There was no difference in the mean stepoff between responders

and nonresponders (2.1 ± 2.2 mm versus 1.9 ± 1.7 mm; $p = 0.13$). The mean gap was slightly smaller in the nonresponders group (2.1 ± 1.3 mm versus 1.7 ± 1.6 mm; $p = 0.02$). There was not much difference in fracture classification between responders and nonresponders (Schatzker I 18% [37 of 203] versus 11% [26 of 242]; Schatzker II 27% [54 of 203] versus 25% [61 of 242]; Schatzker III 39% [80 of 203] versus 35% [85 of 242]; Schatzker IV 12% [25 of 203] versus 16% [39 of 242]; Schatzker V 2% [4 of 203] versus 6% [15 of 242]; Schatzker VI 1% [3 of 203] versus 7% [16 of 242]). Also, there were few differences between responders and nonresponders in fracture classification according on the three-column concept (involvement of one column 58% [118 of 203] versus 52% [127 of 242]; two columns 35% [71 of 203] versus 36% [86 of 242]; three columns 7% [14 of 203] versus 12% [29 of 242]).

RESULTS

Relationship Between Fracture Displacement and Functional Outcome

Nonoperative treatment of minimally displaced tibial plateau fractures resulted in a good functional outcome regardless of the gap (Fig. 2) or stepoff (Fig. 3). KOOS scores in patients with a less than 2 mm, 2 to 4 mm, or more than 4 mm gap did not differ in symptoms (83 ± 17 versus 83 ± 21 versus 82 ± 20 ; $p = 0.98$), pain (85 ± 19 versus 83 ± 22 versus 86 ± 17 ; $p = 0.69$), ADL (87 ± 18 versus 84 ± 21 versus 89 ± 15 ; $p = 0.44$), sports (65 ± 33 versus 64 ± 34 versus 66 ± 33 ; $p = 0.95$), and QOL (70 ± 26 versus 71 ± 28 versus 74 ± 28 ; $p = 0.85$) (Table 2). KOOS scores in patients with a less than 2 mm, 2 to 4 mm, or more than 4 mm stepoff did not differ in symptoms (84 ± 17 versus 83 ± 21 versus 77 ± 20 ; $p = 0.32$), pain (85 ± 20 versus 85 ± 18 versus 81 ± 21 ; $p = 0.66$), ADL (86 ± 19 versus 87 ± 18 versus 82 ± 21 ; $p = 0.54$), sport (65 ± 33 versus 68 ± 30 versus 56 ± 40 ; $p = 0.43$), and QOL (71 ± 26 versus 73 ± 24 versus 61 ± 33 ; $p = 0.19$) (Table 3).

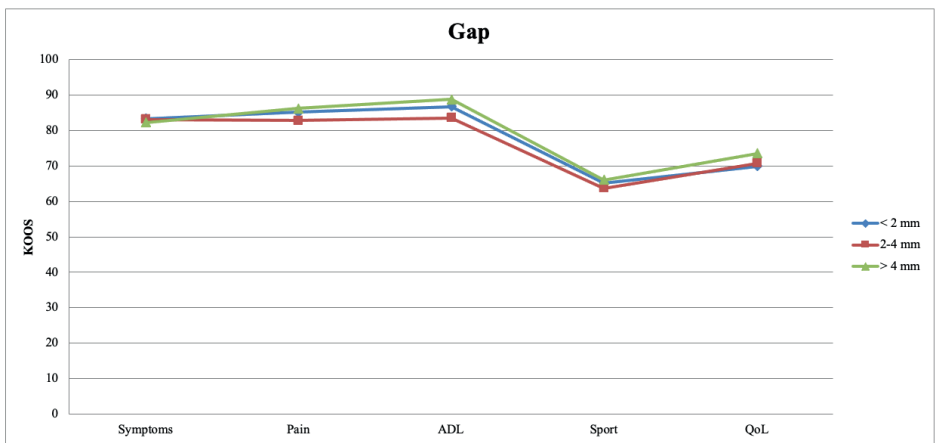


Figure 2 The KOOS subscales, representing functional outcome, are displayed for 196 nonoperatively treated patients divided into three subgroups based on the size of the articular gap. No differences in mean KOOS scores were found between subgroups, meaning that gaps up to 4 mm are well tolerated. Due to the small number of patients in the group with a gap greater than 4 mm, the results of this group need to be interpreted with caution.

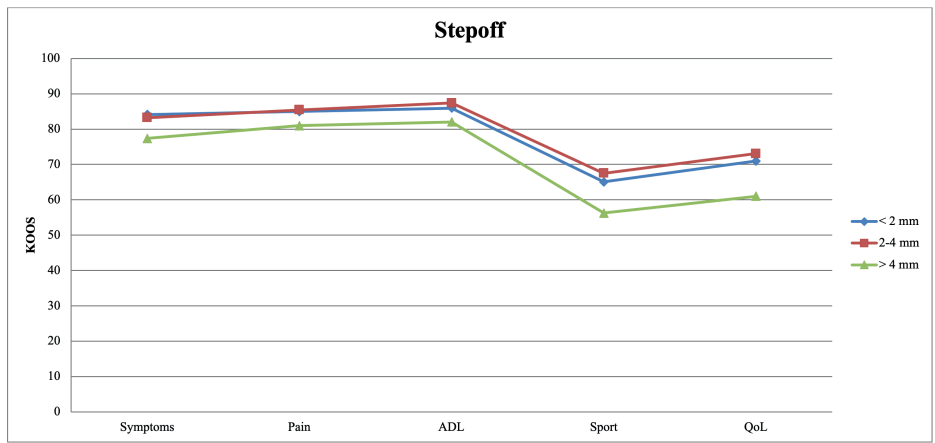


Figure 3 The KOOS subscales, representing functional outcome, are displayed for 196 nonoperatively managed patients divided into three subgroups based on the size of the articular stepoff. No differences in mean KOOS scores were found between subgroups, meaning that stepoffs up to 4 mm are well tolerated. Due to the small number of patients in the group with a stepoff greater than 4 mm, the results of this group need to be interpreted with caution.

Table 2 Size of the articular gap and KOOS scores

Size of articular gap	< 2 mm (n = 114)	2-4 mm (n = 63)	> 4 mm (n = 19)	P-value ^a
KOOS symptoms	83 ± 17	83 ± 21	82 ± 20	0.98
KOOS pain	85 ± 19	83 ± 22	86 ± 17	0.69
KOOS ADL	87 ± 18	84 ± 21	89 ± 15	0.44
KOOS sports	65 ± 33	64 ± 34	66 ± 33	0.95
KOOS QoL	70 ± 26	71 ± 28	74 ± 28	0.85

Data presented as mean ± SD.

^aComparison of KOOS scores (mean ± SD) between groups with increasing gap sizes (< 2 mm, 2 to 4 mm, and > 4 mm).

Table 3 Size of the articular stepoff and KOOS scores

Size of articular stepoff	< 2 mm (n = 119)	2-4 mm (n = 65)	> 4 mm (n = 21)	P-value ^a
KOOS symptoms	84 ± 17	83 ± 21	77 ± 20	0.32
KOOS pain	85 ± 20	85 ± 18	81 ± 21	0.66
KOOS ADL	86 ± 19	87 ± 18	82 ± 21	0.54
KOOS sports	65 ± 33	68 ± 30	56 ± 40	0.43
KOOS QoL	71 ± 26	73 ± 24	61 ± 33	0.19

Data presented as mean ± SD.

^aComparison of KOOS scores (mean ± SD) between groups with increasing stepoff sizes (< 2 mm, 2 to 4 mm, and > 4 mm).

After correction for potential confounders including age, gender, BMI, and the number of columns involved, the linear regression analysis showed there was no relationship between gaps or stepoffs up to 4 mm and the KOOS score (Supplementary Digital Content 1; <https://links.lww.com/CORR/A828>). This applied to each of the five subscales of the KOOS. Stepoffs more than 4 mm were associated with lower scores for symptoms (β : -9.0 [95% CI -17.5 to -0.5]; $p = 0.04$) and QoL (β : -14.0 [95% CI -25.9 to -2.0]; $p = 0.02$).

Conversion to a Total Knee Prosthesis

Survivorship of the knee free from conversion to total knee prosthesis was 97% (95% CI 94% to 99%) at 5 years. Three percent (7 of 203) of patients had a conversion to a total knee prosthesis. The mean age of these patients was 63 ± 3 years. The mean gap was 1.7 ± 1.4 mm and the mean stepoff was 2.3 ± 0.9 mm. Four of 7 patients already had moderate (Kellgren-Lawrence Grade 3) and 3 of 7 had mild (Kellgren-Lawrence Grade 2) preexisting osteoarthritis seen on a radiograph taken at the time of injury. Indications for conversion to total knee prosthesis were progressive posttraumatic osteoarthritis (Kellgren-Lawrence Grade 4).

DISCUSSION

Nonoperative management is considered a good treatment option for minimally displaced tibial plateau fractures [5, 10, 11]. However, there is no consensus about the maximum gap or stepoff that should lead to a recommendation for nonoperative treatment. We evaluated a large cohort of patients with tibial plateau fractures who were treated nonoperatively and correlated CT-determined fracture displacement with functional outcomes after a mean follow-up of 6 ± 3 years. Patients after nonoperative treatment of minimally displaced tibial plateau fractures are generally doing fine. We found that increasing fracture displacement with gaps and/or stepoffs up to 4 mm did not result in poorer functional outcome. The survivorship of the knee, free from conversion to a total knee prosthesis, was high. Based on these findings, we believe that minimally displaced tibial plateau fractures with a gap and/or stepoff up to 4 mm could be treated nonoperatively.

Limitations

We acknowledge that nonresponse bias is inherent to a cross-sectional study design caused by loss to follow-up and nonparticipation [3]. We attempted to reduce the risk of selection bias by approaching all eligible patients. The response proportion was quite high (46%) considering the relatively long follow-up time because patients in the northern part of the Netherlands do not migrate much. Nonresponse analysis showed only minor differences in terms of gender and fracture gap between responders and nonresponders, which does not affect our results. In our study population, results regarding gaps and stepoffs more than 4 mm should be interpreted cautiously because the number of patients in these subgroups was limited. Another limitation was the high variation in the length of follow-up, which ranged from 1 to 15 years (mean 6 ± 3 years), which was also inherent in the cross-sectional study design but does not affect our results. The consequences of gaps and stepoffs after 20 years or 30 years of follow-up are still unknown. Therefore, our findings are applicable for midterm follow-up but not for long-term follow-up. Furthermore, this study did not evaluate prospective longitudinal data about short-term patient outcomes, such as time to return to work or sports. This information could be important for active, high-demand patients during clinical decision-making about treatment options. Finally, this study did not include the region of the tibial plateau (which is possible using fracture maps) where the gaps or stepoffs were located. We tried to do so but found that this was not possible because regions are hard to define properly, and fracture lines often involve multiple regions. We believe that exact localization of fracture displacement warrants 3D fracture assessment. We do not think this limitation disqualifies our findings regarding the relationship between gaps and/or stepoffs and functional outcome because fracture displacement assessment is performed according to clinical practice.

Relationship Between Fracture Displacement and Functional Outcome

Because fracture displacement is so important for determining the indication for surgery and prognosis, we assessed the relationship between the initial fracture displacement (gap and stepoff) and patient-reported outcome (KOOS). Our study revealed that fracture gaps and stepoffs up to 4 mm, as measured on CT images, might result in good functional outcome in patients who consider nonoperative treatment for a minimally displaced tibial plateau fracture. No differences in functional outcomes were found between subgroups with increasing gaps and stepoffs up to 4 mm, meaning that the arbitrary 2-mm gap or stepoff limit could be revisited. There is much controversy about what degree of fracture displacement could be accepted to justify nonoperative treatment of minimally displaced tibial plateau fractures. To our knowledge, the frequently reported 2-mm limit for gaps and stepoffs is arbitrary and seems to be based on radiographs instead of CT and is not supported by clinical evidence from recent studies. A study about fracture displacement in the treatment of tibial plateau fractures focused on the impact of residual gaps and stepoffs after operative treatment [16]. However, results regarding residual fracture displacement cannot be automatically translated to clinical recommendations regarding initial fracture displacement. Studies on initial fracture displacement and functional outcome after nonoperative treatment of tibial plateau fractures are limited. According to recent guidelines, patients with fracture displacements less than 2 mm should opt for nonoperative treatment [12, 13]. However, these guidelines do not specify whether the 2-mm limit applies to gaps and stepoffs, nor do they state which imaging modality should be used to assess gaps and stepoffs. Giannoudis et al. [4] reviewed current evidence on the correlation between articular fracture displacement and the risk of posttraumatic osteoarthritis. For tibial plateau fractures, they concluded that the acceptable range of intraarticular stepoff should be somewhere between 2 and 10 mm [4]. However, most of the articles they referred to were from the 1990s, when measurements of fracture displacement were still performed on plain radiographs, whereas over time, clinical decision-making has become increasingly based on CT images.

Conversion to a Total Knee Prosthesis

Based on our results, patients who consider nonoperative treatment for a minimally displaced tibial plateau fracture could be informed that the survivorship of the native knee, free from conversion to total knee prosthesis, is high. Progressive posttraumatic arthritis with conversion to a total knee prosthesis is considered a worse outcome after tibial plateau fracture treatment [1, 5, 10, 11]. Depending on the fracture type and treatment, the proportion of patients who undergo total knee replacement after tibial plateau fractures has ranged from 4% to 22% [17, 18, 19, 21]. Wasserstein et al. [21] recently performed a large population-based, retrospective, comparative study and reported that after operative treatment, 7.3% of patients underwent conversion to a total knee

prosthesis at 10 years of follow-up, which corresponded to a hazard ratio of 5.3 relative to peers from the general population. However, these numbers represent patient outcomes after surgical management of tibial plateau fractures and do not apply to patients treated without surgery. To our knowledge, there are no studies on conversion to a total knee prosthesis after nonoperative treatment.

Conclusion

Patients with minimally displaced tibial fractures who opt for nonoperative fracture treatment should be told that fracture gaps or stepoffs up to 4 mm, as measured on CT images, could result in good functional outcome. Therefore, the arbitrary 2-mm limit of gaps and stepoffs for tibial plateau fractures could be revisited. The survivorship of the knee free from conversion to a total knee prosthesis at a mean follow-up of 5 years is high. Conversion to a total knee prosthesis mostly occurred in patients older than 60 years who often had preexisting osteoarthritis. These findings can be used as a guide for personalized treatment and shared decision-making in the management of minimally displaced tibial plateau fractures. Large, prospective, cohort studies with high response rates are needed to learn more about the relationship between the degree of fracture displacement and functional recovery after tibial plateau fractures.

REFERENCES

1. Assink N, Kraeima J, Slump CH, et al. Quantitative 3D measurements of tibial plateau fractures. *Sci Rep*. 2019;9:1-9.
2. de Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of the knee injury and osteoarthritis outcome score: a validation study. *Health Qual Life Outcomes*. 2008;6:1-11.
3. Euser AM, Zoccali C, Jager KJ, Dekker FW. Cohort studies: prospective versus retrospective. *Nephron Clin Pract*. 2009;113:c214-c217.
4. Giannoudis PV, Tzioupis C, Papathanassopoulos A, Obakponovwe O, Roberts C. Articular step-off and risk of post-traumatic osteoarthritis. *Evidence today. Injury*. 2010;41:986-995.
5. Jeelani A, Arastu MH. Tibial plateau fractures – review of current concepts in management. *Orthop Trauma*. 2017;31:102-115.
6. Kohn MD, Sassoon AA, Fernando ND. Classifications in brief: Kellgren-Lawrence classification of osteoarthritis. *Clin Orthop Relat Res*. 2016;474:1886-1893.
7. Manidakis N, Dosani A, Dimitriou R, Stengel D, Matthews S, Giannoudis P. Tibial plateau fractures: functional outcome and incidence of osteoarthritis in 125 cases. *Int Orthop*. 2010;34:565-570.
8. Millar SC, Arnold JB, Thewlis D, Fraysse F, Solomon LB. A systematic literature review of tibial plateau fractures: what classifications are used and how reliable and useful are they? *Injury*. 2018;49:473-490.
9. Monticone M, Ferrante S, Salvaderi S, Motta L, Cerri C. Responsiveness and minimal important changes for the knee injury and osteoarthritis outcome score in subjects undergoing rehabilitation after total knee arthroplasty. *Am J Phys Med Rehabil*. 2013;92:864-870.
10. Mthethwa J, Chikate A. A review of the management of tibial plateau fractures. *Musculoskelet Surg*. 2018;102:119-127.
11. Papagelopoulos PJ, Partsinevelos AA, Themistocleous GS, Mavrogenis AF, Korres DS, Soucacos PN. Complications after tibia plateau fracture surgery. *Injury*. 2006;37:475-484.
12. Pelsner P. Controversies in the management of tibial plateau fractures. *SA Orthop J*. 2010;9:75-82.
13. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. *EFORT Open Rev*. 2016;1:225-232.
14. Schatzker J, McBroom R. The tibial plateau fracture. The Toronto experience 1968-1975. *Clin Orthop Relat Res*. 1979;138:94-104.
15. Scott CEH, Davidson E, Macdonald DJ, White TO, Keating JF. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. *Bone Joint J*. 2015;97:532-538.
16. Singleton N, Sahakian V, Muir D. Outcome after tibial plateau fracture: how important is restoration of articular congruity? *J Orthop Trauma*. 2017;31:158-163.
17. Timmers TK, van der Ven DJC, de Vries LS, van Olden GDJ. Functional outcome after tibial plateau fracture osteosynthesis: a mean followup of 6 years. *Knee*. 2014;21:1210-1215.
18. 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;41:1865-1873.
19. van Dreumel RLM, Van Wunnik BPW, Janssen L, Simons PCG, Janzing HMJ. Mid- to long-term functional outcome after open reduction and internal fixation of tibial plateau fractures. *Injury*. 2015;46:1608-1612.

20. Wang Y, Luo C, Zhu Y, et al. Updated three-column concept in surgical treatment for tibial plateau fractures - a prospective cohort study of 287 patients. *Injury*. 2016;47:1488-1496.
21. Wasserstein D, Henry P, Paterson JM, Kreder HJ, Jenkinson R. Risk of total knee arthroplasty after operatively treated tibial plateau fracture. *J Bone Joint Surg Am*. 2014;96:144-150.
22. World Health Organisation. Pacific physical activity guidelines for adults. *Fram Accel Commun Phys Act Guidel*. 2011;1:1-34.

APPENDIX

Table 1 Regression analysis to assess the relationship between the initial fracture gap or stepoff and the KOOS score after nonoperative treatment of tibial plateau fractures

Gap	β^a	95% CI	P-value
Symptoms			
< 2 mm	Ref	Ref	Ref
2-4 mm	-0.4	-6.4 to 5.5	0.89
> 4 mm	-4.0	-13.4 to 5.4	0.40
Pain			
< 2 mm	Ref	Ref	Ref
2-4 mm	-1.9	-8.2 to 4.5	0.56
> 4 mm	1.1	-9.0 to 11.2	0.83
ADL			
< 2 mm	Ref	Ref	Ref
2-4 mm	-1.7	-7.8 to 4.5	0.60
> 4 mm	4.2	-5.5 to 14.0	0.40
Sports			
< 2 mm	Ref	Ref	Ref
2-4 mm	-0.58	-11.6 to 10.4	0.92
> 4 mm	-6.7	-25.7 to 12.2	0.49
QoL			
< 2 mm	Ref	Ref	Ref
2-4 mm	-0.50	-7.9 to 8.9	0.90
> 4 mm	-0.6	-12.7 to 14.0	0.93
Stepoff	β^a	95% CI	P-value
Symptoms			
< 2 mm	Ref	Ref	Ref
2-4 mm	0.1	-6.0 to 6.3	0.97
> 4 mm	-9.0	-17.5 to -0.5	0.04
Pain			
< 2 mm	Ref	Ref	Ref
2-4 mm	2.3	-4.3 to 9.0	0.49
> 4 mm	-5.8	-15.0 to 3.4	0.22
ADL			
< 2 mm	Ref	Ref	Ref
2-4 mm	3.0	-3.4 to 9.4	0.36
> 4 mm	-5.1	-14.0 to 3.8	0.26
Sports			
< 2 mm	Ref	Ref	Ref
2-4 mm	3.8	-7.6 to 15.2	0.51
> 4 mm	-12.0	-27.8 to 3.9	0.14
QoL			
< 2 mm	Ref	Ref	Ref
2-4 mm	4.8	-3.8 to 13.4	0.27
> 4 mm	-14.0	-25.9 to -2.0	0.02

Linear regression was used to analyze the relationship between the gap or stepoff and subscales of the KOOS score; the model was adjusted for potential confounders, including gender, age at the time of injury, BMI, and the number of columns involved; after correction for potential confounders, the linear regression analysis showed there was no relationship between gaps or stepoffs up to 4 mm and the KOOS score; this applied to each of the five subscales of the KOOS; stepoffs > 4 mm were associated with lower scores for symptoms (β : -9.0 [95% CI -17.5 to -0.5]; $p = 0.04$) and QOL score (β : -14.0 [95% CI -25.9 to -2.0]; $p = 0.02$).

^aAdjusted for potential confounders including age, gender, BMI, and the number of columns involved.

Chapter 5



What Is the Patient-reported Outcome and Complication Incidence After Operative Versus Nonoperative Treatment of Minimally Displaced Tibial Plateau Fractures?

Nick Assink, Thijs P. Vaartjes, Christiaan J.S.A. Kramer,
Eelke Bosma, Robert J. Nijveldt, Joost G. ten Brinke,
Reinier de Groot, Harm Hoekstra, Frank F.A. IJpma

This chapter was published in:

Clinical Orthopaedics and Related Research (2024) 482:1744-1752

DOI 10.1097/CORR.0000000000003057

ABSTRACT

Background Much controversy remains about whether minimally displaced tibial plateau fractures should be treated operatively or nonoperatively. It is generally accepted that gaps and stepoffs up to 2 mm can be tolerated, but this assumption is based on older studies using plain radiographs instead of CT to assess the degree of initial fracture displacement. Knowledge regarding the relationship between the degree of fracture displacement and expected functional outcome is crucial for patient counseling and shared decision-making, specifically in terms of whether to perform surgery.

Questions/purposes (1) Is operative treatment associated with improved patient-reported outcomes compared with nonoperative treatment in minimally displaced tibial plateau fractures (fractures with up to 4 mm of displacement)? (2) What is the difference in the risk of complications after operative versus nonoperative treatment in minimally displaced tibial plateau fractures?

Methods A multicenter, cross-sectional study was performed in patients treated for tibial plateau fractures between 2003 and 2019 at six hospitals. Between January 2003 and December 2019, a total of 2241 patients were treated for tibial plateau fractures at six different trauma centers. During that time, the general indication for open reduction and internal fixation (ORIF) was intra-articular displacement of > 2 mm. Patients treated with ORIF and those treated nonoperatively were potentially eligible; 0.2% (4) were excluded because they were treated with amputation because of severe soft tissue damage, whereas 4% (89) were excluded because of coexisting conditions that complicated outcome measurement including Parkinson disease, cerebrovascular accident, or paralysis (conditions causing an inability to walk). A further 2.7% (60) were excluded because their address was unknown, and 1.4% (31) were excluded because they spoke a language other than Dutch. Based on that, 1328 patients were potentially eligible for analysis in the operative group and 729 were potentially eligible in the nonoperative group. At least 1 year after injury, all patients were approached and asked to complete the Knee injury and Osteoarthritis Outcome Scale (KOOS) questionnaire. A total of 813 operatively treated patients (response percentage: 61%) and 345 nonoperatively treated patients (response percentage: 47%) responded to the questionnaire. Patient characteristics including age, gender, BMI, smoking, and diabetes were retrieved from electronic patient records, and imaging data were shared with the initiating center. Displacement (gap and stepoff) was measured for all participating patients, and all patients with minimally displaced fractures (gap or stepoff ≤ 4 mm) were included, leaving 195 and 300 in the operative and nonoperative groups, respectively, for analysis here. Multivariate linear regression was performed to assess the association of treatment choice (nonoperative or operative) with patient-reported outcomes in minimally displaced fractures. In the multivariate analysis, we accounted for nine potential confounders (age, gender, BMI, smoking, diabetes, gap,

stepoff, AO/OTA classification, and number of involved segments). In addition, differences in complications after operative and nonoperative treatment were assessed. The minimum clinically important differences for the five subscales of the KOOS are 11 for symptoms, 17 for pain, 18 for activities of daily living, 13 for sports, and 16 for quality of life.

Results After controlling for potentially confounding variables such as age, gender, BMI, and AO/OTA classification, we found that operative treatment was not associated with an improvement in patient-reported outcomes. Operative treatment resulted in poorer KOOS in terms of pain (-4.7 points; $p = 0.03$), sports (-7.6 points; $p = 0.04$), and quality of life (-7.8 points; $p = 0.01$) compared with nonoperative treatment, but those differences were small enough that they were likely not clinically important. Patients treated operatively had more complications (4% [7 of 195] versus 0% [0 of 300]; $p = 0.01$) and reoperations (39% [76 of 195] versus 6% [18 of 300]; $p < 0.001$) than patients treated nonoperatively. After operative treatment, most reoperations (36% [70 of 195]) consisted of elective removal of osteosynthesis material.

Conclusion No differences in patient-reported outcomes were observed at midterm follow-up between patients treated surgically and those treated nonsurgically for tibial plateau fractures with displacement up to 4 mm. Therefore, nonoperative treatment should be the preferred treatment option in minimally displaced fractures. Patients who opt for nonoperative treatment should be told that complications are rare, and only 6% of patients might undergo surgery by midterm follow-up. Patients who opt for surgery of a minimally displaced tibial plateau fracture should be told that complications may occur in up to 4% of patients, and 39% of patients may undergo a secondary intervention (most of which are elective implant removal).

INTRODUCTION

Tibial plateau fractures with relatively small gaps or stepoffs (up to 4 mm) might be considered minimally displaced [22]. For these injuries, operative and nonoperative management might be suitable. Gap and stepoff measurements, both representing fracture displacement, are often used clinically when deciding between operative and nonoperative treatment [12, 17, 18]. However, whether to choose operative or nonoperative treatment remains a topic of debate in patients with these minimally displaced fractures. Evidence regarding the accepted residual incongruity varies from 2 to 10 mm [6, 15, 16, 20]. For every fracture, it is important to consider whether the advantages of surgery outweigh potential complications, and this process requires shared decision-making.

However, there is very little evidence to support such a shared decision-making process in patients with minimally displaced fractures. The generally accepted indication for proceeding to surgical treatment of tibial plateau fractures includes an intra-articular fracture gap or stepoff of more than 2 mm [7, 17, 18]. This 2-mm cutoff was suggested by research that is more than 30 years old [4, 21], and to our knowledge, there is little support for the assumption that accurate articular reduction of tibial plateau fractures < 2 mm is critical to achieving a good clinical outcome [9]. In our experience, especially in minimally displaced tibial plateau fractures that slightly exceed the 2-mm threshold, there is considerable variation in treatment type across surgeons and centers. Despite the substantial impact of these injuries on patients and healthcare systems, evidence on this topic is scarce, and comparative studies between nonoperative and operative treatment of minimally displaced tibial plateau fractures are lacking. In addition, current studies are limited to residual displacement postoperatively, which does not allow for recommendations regarding how to treat fractures based on the initial displacement. A recent study demonstrated that initial fracture gaps or stepoffs up to 4 mm, as measured on CT, could result in good functional outcome after nonoperative treatment [22]; thus, it seems reasonable to revisit the old recommendation of a threshold of 2 mm based on radiographs and to see whether the threshold should be revised based on evolving insights from CT images.

We therefore asked: (1) Is operative treatment associated with improved patient-reported outcomes compared with nonoperative treatment in minimally displaced tibial plateau fractures (fractures with up to 4 mm of displacement)? (2) What is the difference in the risk of complications after operative versus nonoperative treatment in minimally displaced tibial plateau fractures?

PATIENTS AND METHODS

Study Design and Setting

A multicenter, cross-sectional study was performed in patients treated for a tibial plateau fracture between January 2003 and December 2019 in the orthopaedic and trauma surgery department of six hospitals (four Level 1 and two Level 2 trauma centers). Hospitals consisted of two academic centers and four nonacademic centers in medium-sized cities in the Netherlands and Belgium.

Participants

Between January 2003 and December 2019, a total of 2241 patients were treated for tibial plateau fractures, had an available diagnostic CT scan, and were still alive at the time of follow-up, according to the national population registry. Patients treated with open reduction and internal fixation (ORIF) and those treated nonoperatively were potentially eligible; a total of 0.2% (4) were excluded because they underwent amputation owing to severe soft tissue damage, whereas 4% (89) were excluded because of coexisting conditions complicating outcome measurement, including Parkinson disease, cerebrovascular accident, or paralysis (that is, conditions causing an inability to walk). A further 2.7% (60) were excluded because their address was unknown, and 1.4% (31) were excluded because they spoke a language other than Dutch. Thus, 1328 patients were potentially eligible for analysis in the operative group and 729 were potentially eligible in the nonoperative group. At least 1 year after injury, all patients were approached and asked to complete the Knee injury and Osteoarthritis Outcome Scale (KOOS) questionnaire. A total of 813 operatively treated patients (response percentage: 61%) and 345 nonoperatively treated patients (response percentage: 47%) responded to the questionnaire. Patient characteristics including age, gender, BMI, smoking, and diabetes were retrieved from electronic patient records, and imaging data were shared with the initiating center. Displacement (gap and stepoff) was measured for all participating patients, and all patients with minimally displaced fractures (gap or stepoff ≤ 4 mm) were included, leaving 195 and 300 in the operative and nonoperative groups, respectively, for analysis here (Fig. 1).

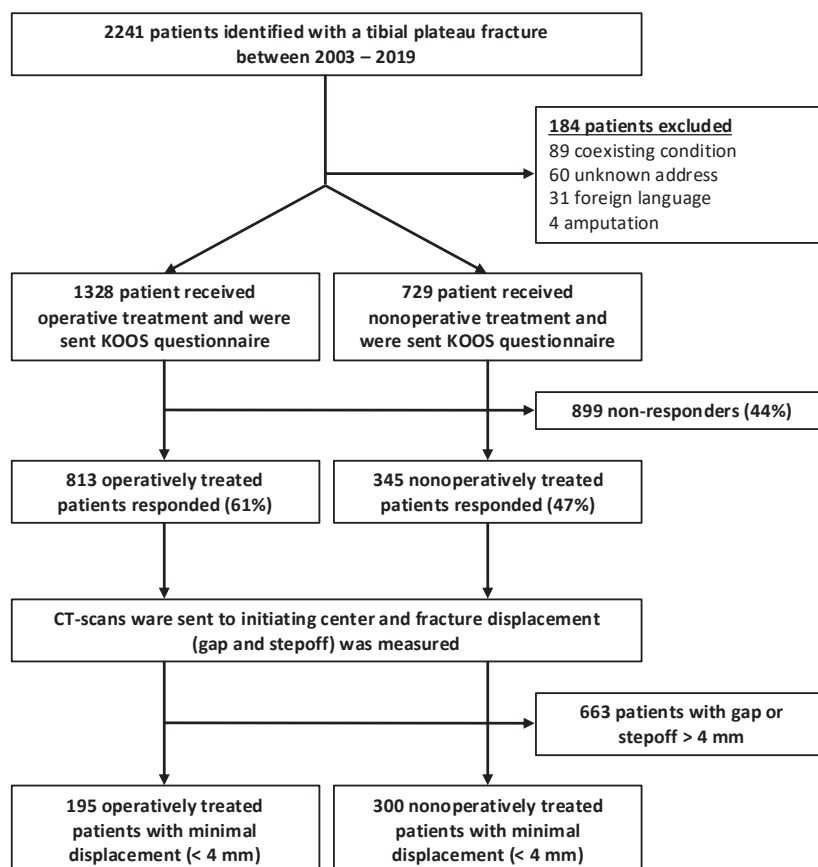


Figure 1 The patient inclusion process for this study is depicted in this flowchart.

Analysis of Nonresponders

For the nonresponse analysis, we used an independent-samples t-test for continuous variables and a chi-square test for noncontinuous variables. Overall, nonresponders did not differ very much from responders, which tends to lend credibility to the analysis. The nonresponse analysis showed that nonresponders were slightly younger than responders (51 ± 18 years versus 53 ± 16 years; $p = 0.001$), there was a smaller proportion of women (58% [523 of 896] versus 68% [788 of 1155]; $p = 0.001$), and they received nonoperative treatment more often (43% [387 of 896] versus 30% [345 of 1155]; $p = 0.001$). Knee radiographs and CT images of nonresponders at the initiating center and one affiliated center were the only ones available for the imaging analysis ($n = 550$). Analysis showed that nonresponders in these centers had smaller gaps (4.2 ± 5.2 mm versus 6.4 ± 6.3 mm; $p < 0.001$) and stepoff (4.5 ± 4.7 mm versus 6.3 ± 5.7 mm; $p < 0.001$). AO/OTA

fracture classification did not differ between nonresponders and responders (B1: 11% versus 15%, B2: 16% versus 19%, B3: 45% versus 39%, C2: 6% versus 8%, C3: 22% versus 17%; $p = 0.26$).

Descriptive Data

Patients who received operative treatment for minimally displaced tibial plateau fractures did not differ from nonoperatively treated patients in terms of mean $\pm$ standard deviation age (51 ± 15 years versus 54 ± 16 years; $p = 0.09$), gender (64% [125 of 195] versus 72% [216 of 300] women; $p = 0.07$), BMI (26 ± 4 kg/m² versus 26 ± 5 kg/m²; $p = 0.22$), smoking (21% [40 of 195] versus 17% [50 of 300]; $p = 0.38$), and diabetes (7% [13 of 195] versus 8% [23 of 300]; $p = 0.58$) (Table 1). Operatively treated fractures consisted of split depression fractures (AO/OTA B3), whereas nonoperatively treated fractures consisted more often of pure split (AO/OTA B1) and pure depression (AO/OTA B2) fractures ($p < 0.001$). Additionally, operatively treated fractures had slightly more articular segments involved (4 ± 2 versus 3 ± 1 ; $p < 0.001$) (Table 1).

Table 1 Patient characteristics of patients with a minimally displaced tibial plateau fracture (gap and stepoff ≤ 4 mm)

Parameter	Operative (n = 195)	Nonoperative (n = 300)	P-value
Age in years	51 ± 15	54 ± 16	0.09
Women	64% (125)	72% (216)	0.07
BMI in kg/m ²	26 ± 4	26 ± 5	0.22
Smoking	21% (40)	17% (50)	0.38
Diabetes	7% (13)	8% (23)	0.58
AO/OTA classification			< 0.001
41-B1	15% (30)	25% (75)	
41-B2	32% (62)	44% (133)	
41-B3	44% (85)	26% (77)	
41-C1	5% (9)	4% (12)	
41-C2	2% (4)	0% (1)	
41-C3	2% (5)	1% (2)	
Number of involved segments (10-segment classification)	4 ± 2	3 ± 1	< 0.001
Follow-up in years	7 ± 4	6 ± 3	0.06

Data presented as mean $\pm$ SD or % (n).

Image Review and Gap and Stepoff Measurements

All knee radiographs and CT images that were taken at the time of injury were reassessed through consensus by an attending orthopaedic trauma surgeon (FFAIJ, > 10 years of experience) and technical physician (NA, > 5 years of experience). Fracture classification was

determined according to the AO/OTA and 10-segment classification system [8, 13]. Based on fracture characteristics, the AO/OTA classification classifies intraarticular tibial plateau fractures into different types of fractures: partial articular fractures (B1: pure split, B2: pure depression, B3: split-depression) or complete articular fractures (C1: simple articular and metaphyseal, C2: articular simple and metaphyseal multifragmentary, C3: articular multifragmentary) [13]. The 10-segment classification divides the plateau into 10 segments; more involvement of segments indicates a more extensive fracture [8]. Preoperative CT images were reassessed in the axial, sagittal, and coronal planes; in addition, gap and stepoff measurements were performed on the CT slice where displacement was found to be the highest. Gap was defined as separation of fracture fragments along the articular surface, and stepoff was characterized as separation of fracture fragments perpendicular to the articular surface [2, 22]. For each patient, the maximum value of the gap and stepoff on any of the axial, coronal, or sagittal CT slices is reported. To assess the impact of gap and stepoff separately, a subanalysis was performed in which patients were divided into four groups based on the size of their maximum gap and stepoff: patients with a gap and stepoff less than 2 mm, patients with a gap between 2 and 4 mm and stepoff less than 2 mm, patients with a stepoff between 2 and 4 mm and gap less than 2 mm, and patients with a gap and stepoff between 2 and 4 mm (Fig. 2).

Patient-reported Outcomes

All eligible patients were approached by postal mail and asked to provide informed consent and complete the validated and standardized KOOS questionnaire in Dutch [5]. The KOOS is a questionnaire designed to assess short-term and long-term patient-relevant outcomes after knee injuries. It contains 42 items in five separately scored subscales: pain, symptoms, activities of daily living (ADL), function in sport and recreation (sports), and quality of life (QoL). We calculated subscale scores by adding the individual items (questions) and transforming scores to a range from 0 to 100, with higher scores indicating better function. The minimum clinically important differences for the five subscales of the KOOS are 11 for symptoms, 17 for pain, 18 for ADL, 13 for sports, and 16 for QOL [11].

Data Sources

Baseline characteristics of the participants were retrieved from the patients' electronic records. KOOS scores were calculated from the returned patient questionnaires. Gap and stepoff measurements were performed on diagnostic CT images.

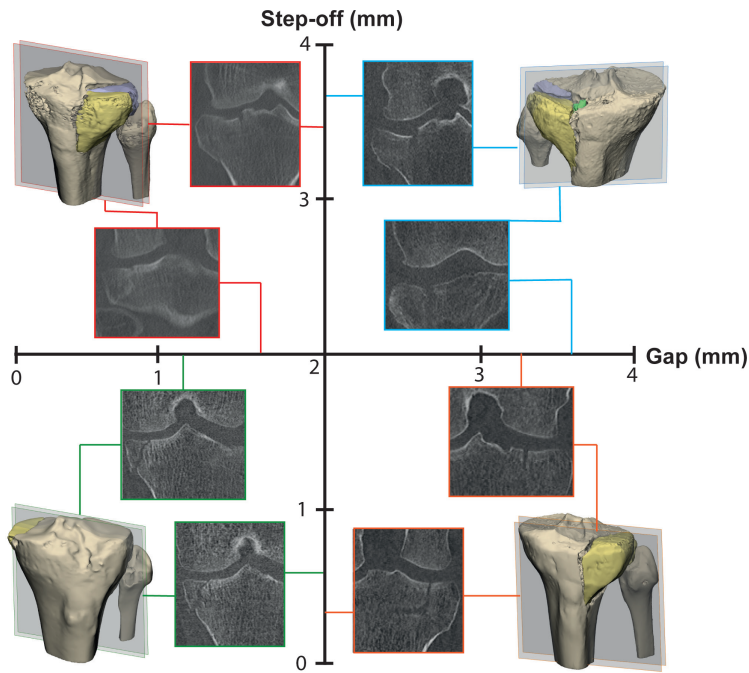


Figure 2 Based on their gap and stepoff patients were divided into four groups: stepoff between 2 and 4 mm and gap less than 2 mm (upper left), gap and stepoff between 2 and 4 mm (upper right), gap and stepoff less than 2 mm (lower left), gap between 2 and 4 mm and stepoff less than 2 mm (lower right). This illustrates the different combinations of sizes of gaps and step-offs which are consider minimally displaced fractures.

Primary and Secondary Study Goals

The primary study goal was to assess patient-reported outcomes after nonoperative and operative treatment of minimally displaced tibial plateau fractures. To assess the impact of gap and stepoff separately, a subanalysis was performed in which patients were divided into four groups with varying sizes of gap and stepoff. In addition, we performed multivariate regression to assess the association of treatment choice with patient-reported outcomes when accounting for patient characteristics and fracture characteristics (size, classification, and location). Our secondary goal was to report the incidence of complications after nonoperative or operative treatment of minimally displaced tibial plateau fractures.

Ethical Approval

The institutional review board of all centers involved approved the study procedures, and the study was performed in accordance with relevant guidelines and regulations. All participants signed an informed consent form, and their imaging data were transferred to the initiating center.

Statistical Analysis

The statistical analysis was performed using SPSS (version 28, IBM Corp). Differences in characteristics between operatively and nonoperatively treated patients were assessed using a t-test for continuous variables and a chi-square test for noncontinuous variables. We performed an analysis of variance test to assess the difference in patient-reported outcomes between patients in the nonoperative group and those in the operative group. We performed multivariate linear regression to assess the association of treatment choice (nonoperative or operative) with patient-reported outcomes in minimally displaced fractures. The analysis accounted for nine potential confounders (age, gender, BMI, smoking, diabetes, gap, stepoff, AO/OTA classification, and number of involved segments, according to the definition of Krause et al. [8]). Power analysis revealed that with $\alpha = 0.05\%$, a sample size of 126 patients (63 in the operative group and 63 in the nonoperative group) was required to provide 80% power to detect a difference of 11 points in the KOOS score (minimum clinically important difference), with a standard deviation of 20. A chi-square test was performed to assess differences in the incidence of complications and additional surgeries after operative and nonoperative treatment. A p value of less than 0.05 was considered statistically significant.

RESULTS

Patient-Reported Outcomes After Operative Versus Nonoperative Treatment

After controlling for potential confounding variables including age, gender, BMI, smoking, diabetes, gap, stepoff, AO/OTA classification, and number of involved segments, we found no clinically important difference between operative and nonoperative treatment in terms of all subscales of the KOOS questionnaire (Table 2, Supplemental Table 1; <http://links.lww.com/CORR/B290>). Operative treatment resulted in poorer KOOS score in terms of pain (-4.7 points; $p = 0.03$), sports (-7.6 points; $p = 0.045$), and QoL (-7.8 points; $p = 0.01$) compared with nonoperative treatment. However, this difference did not reach the point that was considered clinically important (Supplemental Table 2; <http://links.lww.com/CORR/B290>).

Table 2 Multivariate regression analysis of the association between choice for operative treatment and patient-reported outcome in minimally displaced tibial plateau fractures^a

	β (95% CI)	P-value
KOOS symptoms	-3.7 (-7.8 to 0.4)	0.08
KOOS pain	-4.7 (-9.0 to -0.3)	0.03
KOOS ADL	-3.5 (-7.7 to 0.7)	0.10
KOOS sport	-7.6 (-15.0 to -0.2)	0.045
KOOS QoL	-7.8 (-13.5 to -2.1)	0.01

The β values indicate the average increase in KOOS value associated with the choice of an operative instead of nonoperative treatment. This means that choice for operative treatment reduces the functional outcome in terms of KOOS symptoms; for example, 3.7 points compared with nonoperative treatment when accounting for confounders.

^aIncluded confounders: age, gender, BMI, smoking, diabetes, gap, stepoff, AO/OTA classification, and involved segments.

Complications and Additional Surgical Procedures

Patients treated operatively had more complications (4% [7 of 195] versus 0% [0 of 300]; $p = 0.01$) and reoperations (39% [76 of 195] versus 6% [18 of 300]; $p < 0.001$) than patients treated nonoperatively. After operative treatment, most reoperations (36% [70 of 195]) consisted of elective removal of osteosynthesis material (Table 3).

Table 3 Complications and additional surgery

	Operative (n = 195)	Nonoperative (n = 300)	P-value
Complications	4% (7)	0% (0)	0.01
Fracture-related infection	2% (4)	0% (0)	
Peroneal nerve neurapraxia	2% (3)	0% (0)	
Additional surgery	39% (76) ^a	6% (18)	<0.001
Revision for meniscal or ligamentous damage	2% (3)	3% (10)	
Corrective osteotomy after malunion	0.5% (1)	0.3% (1)	
Elective removal of osteosynthesis material	36% (70)	0% (0)	
Conversion to TKA	4% (7)	2% (7)	

Data are presented as % (n).

^aEighty-one additional surgical procedures were performed in these 76 patients.

DISCUSSION

Whether minimally displaced tibial plateau fractures should be treated operatively or nonoperatively remains controversial. There is no consensus regarding whether the generally used indication for operative treatment based on fracture displacement greater than 2 mm is crucial for attaining a good clinical outcome [9, 22]. We evaluated a large

cohort of patients with tibial plateau fractures with minimal displacement to assess whether this recommendation based on radiographs could be justified or whether this should be revisited based on evolving insights from CT images. We found that regardless of the treatment type, no clinically important differences in patient-reported outcomes were seen at midterm follow-up. Among the patients who underwent operative treatment, 4% had a complication, and 39% of the operatively treated patients underwent one or more additional surgical procedures, often in the form of elective implant removal (36% [70 of 195]). Based on these findings, we believe that nonoperative treatment should be considered the preferred treatment option in patients with minimally displaced tibial plateau fractures with gaps and stepoffs up to 4 mm.

Limitations

We acknowledge that this study has some degree of response bias, which is inherent to the cross-sectional study design caused by loss to follow-up and nonresponse. By approaching all patients multiple times, we reduced the risk of nonresponse bias as much as possible. In fact, our response proportion of 56% (61% for operatively treated patients and 47% for nonoperatively treated patients) is in line with what could be expected from a postal survey according to the existing evidence [10]. Nonresponse analysis showed only minor differences in terms of gender and age between responders and nonresponders, which would not affect our results. However, nonresponders were treated nonoperatively more frequently and had less displacement in terms of gap and stepoff, and it is possible that missing patients are not doing as well as those who were accounted for. Another limitation caused by the cross-sectional study design was the variation in the length of follow-up, which ranged from 1 to 17 years (mean 6 years). The consequences of gaps and stepoffs at long-term follow-up (20+ years) are still unknown. Therefore, our findings are applicable for midterm follow-up but should be interpreted with caution regarding long-term follow-up. Lastly, this study focused on fracture displacement in terms of gaps and stepoffs. However, the location and extent of the fracture might also affect the choice of operative or nonoperative treatment. By quantifying the extent of the fracture through an evaluation of the number of involved segments, as defined by Krause et al. [8], we corrected for this confounding factor in our analysis. Therefore, we do not think this limitation disqualifies our findings.

Patient-Reported Outcomes After Operative Versus Nonoperative Treatment

Regardless of the treatment type, no clinically important differences in patient-reported outcomes at midterm follow-up were found in this study. Many current guidelines on the treatment of tibial plateau fractures include an intra-articular fracture gap or stepoff of greater than 2 mm as an indication for surgical treatment [7, 17, 18]. Yet, with no expected difference in functional outcome between operative and nonoperative treatment, our

results suggest that nonoperative treatment might be preferred in patients with minimally displaced fractures with initial gaps and stepoffs up to 4 mm. Much controversy remains regarding the level of articular incongruity that would be considered acceptable to justify nonoperative treatment [6]. One review of the current evidence on the correlation between residual articular fracture displacement and the risk of posttraumatic osteoarthritis concluded that the acceptable range of intra-articular stepoff should be between 2 and 10 mm [6]. By contrast, Singleton et al. [20] reported that patients with less than 2.5 mm of residual articular depression had improved outcomes. However, both studies reported on residual instead of initial fracture displacement as in our study, and therefore these results cannot automatically be translated to clinical recommendations regarding initial fracture displacement. A recent study showed that nonoperative treatment of minimally displaced fractures with initial gaps and stepoffs up to 4 mm results in good patient-reported outcomes [22]. However, this study did not directly compare nonoperatively and operatively treated patients.

One could argue that some patients with displacement exceeding the 2-mm threshold in our study might have received nonoperative treatment because of other patient-related factors such as age or comorbidities. However, this was probably not the case because patients who were treated operatively and nonoperatively in this study did not differ in terms of patient characteristics such as age, gender, BMI, smoking, and diabetes. Regarding fracture characteristics, fractures that were treated operatively seemed to involve a slightly larger area of the tibial plateau than nonoperatively treated fractures (4 ± 2 segments versus 3 ± 1 segments as defined by Krause et al. [8]). We conducted a multivariable analysis to account for these confounding factors, and it reconfirmed our findings that nonoperative treatment was noninferior to operative treatment in minimally displaced fractures with gaps and stepoffs up to 4 mm. Future studies to gain more evidence on this topic should include multicenter, prospective registry studies, preferably with preoperative and postoperative CT images and three-dimensional fracture analysis of initial and residual fracture displacement [1, 3].

Complications and Additional Surgical Procedures

We found that operative management of minimally displaced fractures was associated with a higher chance of complications and likelihood of return to our clinic for additional surgery. Although relatively rare in minimally displaced fractures, complications such as infections and neuropraxia can severely impact patients' well-being [14]. Subjecting the patient to further surgeries introduces this risk once again. A surgeon should be thoughtful before recommending surgery, and choosing a treatment for tibial plateau fractures should involve a discussion about whether the surgical advantages outweigh the potential complications. This is especially true for minimally displaced fractures for which the advantages of surgery (such as minimal fracture reduction to reduce the risk

of posttraumatic osteoarthritis) might be limited. After all, surgery is not without risks. A recent systematic review including 2214 procedures reported surgical site infections in 9.9% of patients after surgical treatment of tibial plateau fractures [19]. The minimally displaced fractures evaluated in this study had a lower infection incidence of 2%. Injury of the peroneal nerve was observed in 2% of patients. Additionally, 36% (70 patients) underwent removal of osteosynthesis material at follow-up, exposing patients to additional risks associated with surgical treatment. None of these complications were reported in the nonoperative treatment group. Although patients in the nonoperative treatment group had a number of revisions for meniscal or ligamentous damage, these numbers were lower than in the patients who had operative treatment. Reducing the risk of posttraumatic arthritis at follow-up might still be a reason to opt for operative treatment, but at midterm follow-up, we found no advantage to surgery, because there was no difference between patients treated nonoperatively and those treated operatively in terms of the proportion undergoing conversion to TKA (2% versus 4%). Future prospective studies might provide a more comprehensive overview of complications and reinterventions.

Conclusion

Regardless of the treatment type, no differences in patient-reported outcomes were seen at midterm follow-up when patients treated surgically and those treated nonsurgically for tibial plateau fractures with displacement up to 4 mm were compared. Therefore, nonoperative treatment should be considered the preferred treatment in minimally displaced fractures. Patients who opt for nonoperative treatment should be told that complications are rare and only 6% of patients might require surgery at a later stage. Patients who choose surgery should be told that complications may occur in up to 4% of patients, and 39% of patients may undergo a secondary intervention (36% of patients an elective implant removal procedures).

REFERENCES

1. Assink N, Bosma E, Meesters AML, et al. Initial and residual 3D fracture displacement is predictive for patient-reported functional outcome at mid-term follow-up in surgically treated tibial plateau fractures. *J Clin Med*. 2023;12:6055.
2. Assink N, El Moumni M, Kraeima J, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery: results in a large multicenter cohort. *J Bone Joint Surg Am*. 2023;105:1237-1245.
3. Assink N, Kraeima J, Meesters AML, et al. 3D assessment of initial fracture displacement of tibial plateau fractures is predictive for risk on conversion to total knee arthroplasty at long-term follow-up. *Eur J Trauma and Emerg Surg*. 2022;49:867-874.
4. Brown TD, Anderson DD, Nepola J V, Singerman RJ, Pedersen DR, Brand RA. Contact stress aberrations following imprecise reduction of simple tibial plateau fractures. *J Orthop Res*. 1988;6:851-862.
5. De Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of the Knee Injury and Osteoarthritis Outcome Score: a validation study. *Health Qual Life Outcomes*. 2008;6:1-11.
6. Giannoudis P V., Tzioupis C, Papathanassopoulos A, Obakponovwe O, Roberts C. Articular stepoff and risk of post-traumatic osteoarthritis. Evidence today. *Injury*. 2010;41:986-995.
7. Hall JA, Beuerlein MJ, McKee MD, Canadian Orthopaedic Trauma Society. Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures. Surgical technique. *J Bone Joint Surg Am*. 2009;91:74-88.
8. Krause M, Preiss A, Müller G, et al. Intra-articular tibial plateau fracture characteristics according to the "Ten segment classification." *Injury*. 2016;47:2551-2557.
9. Marsh JL, Buckwalter J, Gelberman R, et al. Articular fractures: Does an anatomic reduction really change the result? *J Bone Joint Surg Am*. 2002;84:1259-71.
10. Meyer VM, Benjamins S, El Moumni M, Lange JFM, Pol RA. Global overview of response rates in patient and health care professional surveys in surgery: a systematic review. *Ann Surg*. 2022;275:e75-e81.
11. Monticone M, Ferrante S, Salvaderi S, Motta L, Cerri C. Responsiveness and minimal important changes for the Knee Injury and Osteoarthritis Outcome Score in subjects undergoing rehabilitation after total knee arthroplasty. *Am J Phys Med Rehabil*. 2013;92:864-870.
12. Mthethwa J, Chikate A. A review of the management of tibial plateau fractures. *Musculoskelet Surg*. 2018;102:119-127.
13. Müller ME, Nazarian S, Koch P, Schatzker J. The comprehensive classification of fractures of long bones. Springer. 1990.
14. Papagelopoulos PJ, Partsinevelos AA, Themistocleous GS, Mavrogenis AF, Korres DS, Soucacos PN. Complications after tibia plateau fracture surgery. *Injury*. 2006;37:475-484.
15. Parkkinen M, Lindahl J, Mäkinen TJ, Koskinen SK, Mustonen A, Madanat R. Predictors of osteoarthritis following operative treatment of medial tibial plateau fractures. *Injury*. 2018;49:370-375.
16. Parkkinen M, Madanat R, Mustonen A, Koskinen SK, Paavola M, Lindahl J. Factors predicting the development of early osteoarthritis following lateral tibial plateau fractures: Mid-term clinical and radiographic outcomes of 73 operatively treated patients. *Scand J Surg*. 2014; 103:256-62.

17. Pelser P. Controversies in the management of tibial plateau fractures. *SA Orthopaedic Journal*. 2010;9:75-82.
18. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: An update. *EFORT Open Rev*. 2017;1:225-232.
19. Shao J, Chang H, Zhu Y, et al. Incidence and risk factors for surgical site infection after open reduction and internal fixation of tibial plateau fracture: a systematic review and meta-analysis. *Int J Surg*. 2017;41:176-182.
20. Singleton N, Sahakian V, Muir D. Outcome after tibial plateau fracture: how important is restoration of articular congruity? *J Orthop Trauma*. 2017;31:158-163.
21. Tscherne H, Lobenhoffer P. Tibial plateau fractures: Management and expected results. *Clin Orthop Relat Res*. 1993;292:87-100.
22. Vaartjes TP, Assink N, Nijveldt RJ, et al. Functional outcome after nonoperative management of tibial plateau fractures in skeletally mature patients: what sizes of gaps and stepoffs can be accepted? *Clin Orthop Relat Res*. 2022;480:2288-2295.

APPENDIX

Table 1 Full regression model for treatment type in relation to KOOS functional outcome

	KOOS-symptoms (R ² =0.09, adjusted R ² =0.07)		KOOS-pain (R ² =0.09, adjusted R ² =0.07)		KOOS-ADL (R ² =0.10, adjusted R ² =0.08)		KOOS-sport (R ² =0.09, adjusted R ² =0.07)		KOOS-QoL (R ² =0.10, adjusted R ² =0.08)	
	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value	β (95% CI)	P-value
Operative Treatment	-3.7 (-7.7 to 0.4)	0.08	-4.7 (-9.0 to -0.4)	0.03	-3.5 (-7.7 to 0.7)	0.10	-7.6 (-15.0 to -0.2)	0.045	-7.8 (-13.5 to -2.1)	0.01
Age	0.2 (0.1 to 0.4)	<0.001	0.2 (0.0 to 0.3)	0.01	-0.1 (-0.1 to 0.1)	0.46	0.1 (-0.1 to 0.3)	0.25	0.3 (0.1 to 0.4)	<0.001
Male	6.7 (2.8 to 10.5)	<0.001	5.6 (1.6 to 9.7)	0.01	5.1 (1.1 to 8.9)	0.01	13.4 (6.5 to 20.3)	<0.001	7.0 (1.7 to 12.3)	0.01
BMI	-0.8 (-1.1 to -0.4)	<0.001	-1.0 (-1.4 to -0.6)	<0.001	-1.2 (-1.6 to -0.8)	<0.001	-1.8 (-2.5 to -1.1)	<0.001	-1.4 (-1.9 to -0.9)	<0.001
Smoking	-4.8 (-9.3 to -0.2)	0.04	-6.4 (-11.2 to -1.6)	0.01	-8.0 (-12.6 to -3.2)	<0.001	-12.5 (-20.6 to -4.2)	0.01	-5.8 (-12.1 to 0.5)	0.07
Diabetes	0.2 (-6.4 to 6.7)	0.96	1.7 (-5.2 to 8.7)	0.63	3.3 (-3.4 to 10.1)	0.33	5.0 (-7.2 to 17.1)	0.42	1.2 (-7.9 to 10.3)	0.79
Gap	1.2 (-0.8 to 3.2)	0.24	0.3 (-1.8 to 2.3)	0.80	0.6 (-1.4 to 2.7)	0.53	0.7 (-2.9 to 4.3)	0.69	-0.4 (-3.2 to 2.3)	0.76
Stepoff	0.5 (-1.4 to 2.4)	0.63	0.8 (-1.2 to 2.8)	0.43	0.7 (-1.3 to 2.6)	0.51	0.6 (-2.9 to 4.1)	0.73	0.9 (-1.8 to 3.5)	0.53
AO/OTA	-0.03 (-2.0 to 1.9)	0.98	0.8 (-1.2 to 2.9)	0.43	1.3 (-0.7 to 3.3)	0.22	0.4 (-3.1 to 3.9)	0.83	1.7 (-1.1 to 4.4)	0.23
Involved Segments	-0.5 (-1.6 to 0.6)	0.38	0.5 (-1.1 to 1.2)	0.94	-0.5 (-1.7 to 0.6)	0.36	-0.3 (-2.3 to 1.8)	0.80	-0.4 (-1.9 to 1.2)	0.64

Table 2 Patient-reported outcomes after operative versus nonoperative treatment of minimally displaced tibial plateau fractures, stratified according to increasing fracture displacement

	Gap and stepoff < 2 mm		Gap 2-4 mm (and stepoff < 2 mm)		Stepoff 2-4 mm (and gap < 2 mm)		Gap and stepoff 2-4 mm		P-value
	Operative (n = 28)	Nonoperative (n = 169)	Operative (n = 36)	Nonoperative (n = 45)	Operative (n = 53)	Nonoperative (n = 56)	Operative (n = 78)	Nonoperative (n = 30)	
KOOS – symptoms	79 ± 16	80 ± 20	76 ± 21	86 ± 13	83 ± 18	83 ± 19	78 ± 23	85 ± 16	0.03 ^a
KOOS – pain	78 ± 20	81 ± 21	78 ± 22	87 ± 17	85 ± 18	84 ± 19	77 ± 23	86 ± 18	0.03 ^a
KOOS - ADL	82 ± 20	83 ± 21	82 ± 20	89 ± 17	87 ± 16	85 ± 19	81 ± 23	87 ± 18	0.19
KOOS - sport	54 ± 36	56 ± 35	50 ± 32	69 ± 32	56 ± 36	59 ± 32	52 ± 37	59 ± 35	0.03
KOOS - QoL	61 ± 26	68 ± 27	61 ± 27	72 ± 22	67 ± 26	71 ± 25	61 ± 32	74 ± 27	0.01 ^a

Data presented as mean ± SD.

When stratifying groups based on the size of the gap and stepoff, operative treatment resulted in slightly lower patient-reported outcome than nonoperative treatment in terms of KOOS symptoms, pain, sports, and quality of life. A clinically important difference was only found in terms of sports in patients with a gap between 2 and 4 mm and stepoff < 2 mm.

Minimum clinically important differences: KOOS-symptoms = 11, KOOS-pain = 17, KOOS-ADL = 18, KOOS-sport = 13, and KOOS-QoL = 16.

^a Difference unlikely to be clinically important.

Chapter 6



What Is the Association Between Radiographic Measurements of Initial and Residual Fracture Displacement, Tibial Alignment, and Recovery in Terms of Patient-reported Outcome After Surgical Treatment of Tibial Plateau Fractures?

Thijs P. Vaartjes, Eelke Bosma, Sven H. van Helden, Joost G. ten Brinke,
Reinier de Groot, Inge H.F. Reininga, Job N. Doornberg, Harm Hoekstra,
Nick Assink, Frank F.A. IJpma

This chapter was published in:
Clinical Orthopaedics and Related Research (2026) 484:520-529
DOI 10.1097/CORR.0000000000003727

ABSTRACT

Background In tibial plateau fracture surgery, radiographic measurements are used to assess preoperative fracture displacement and postoperative results. However, the association between these values and patients' clinical outcomes remains unclear.

Questions/purposes (1) What is the association between preoperative fracture displacement (gap and stepoff), as assessed on CT scans, and full recovery in terms of patient-reported outcome (Knee injury and Osteoarthritis Outcome Score [KOOS] scores within the minimum clinically important difference [MCID] range of population-based normative values)? (2) What is the association between postoperative fracture reduction and knee alignment, as assessed on radiographs, and full recovery in terms of patient-reported outcome?

Methods A multicenter cross-sectional study was performed including all patients with tibial plateau fractures who were treated surgically between 2003 and 2019 in five trauma centers. During that time, 1121 patients had surgery for these injuries; all were asked to complete the KOOS questionnaire, measured on a scale of 0 to 100 points (100 indicating no problems and 0 indicating severe problems). The general indications for surgery during this time were an initial gap and/or stepoff greater than 2 mm and inadequate coronal and sagittal tibial alignment. In all, 58% (645 of 1121) of patients responded after a mean 6 SD follow-up of 7 6 4 years, the mean age was 52 ± 14 years, and 68% (436 of 645) were women. Nonresponse analysis showed no substantial differences in patient characteristics and fracture classification between those who did and who did not respond. Independent observers reassessed and classified all pre- and postoperative CT images and radiographs according to the Schatzker classification. Initial fracture displacement (gap and stepoff) was measured on preoperative CT scans. The gap was defined as a separation between fracture fragments along the articular surface, and the stepoff was defined as a separation of fracture fragments perpendicular to the articular surface. Residual incongruence (maximum gap and/or stepoff), condylar widening, and tibial alignment (medial proximal tibial angle [MPTA]), as well as posterior proximal tibial angle [PPTA]), were measured on postoperative radiographs. Patients were classified as having achieved full recovery when KOOS scores were within the MCID range of KOOS scores from normative data from the general population (data from age-related peers). Binary logistic regression analyses were performed to assess the association between preoperative fracture displacement or postoperative fracture reduction and full recovery (KOOS scores within the MCID range of population-based normative values). The models were adjusted for gender, Schatzker classification, BMI, complications, postoperative fracture reduction, and follow-up time.

Results Preoperative radiographic assessment demonstrated that substantial initial fracture displacement (> 10 mm gap or > 8 mm stepoff) was independently associated with increased odds of not reaching full recovery, again defined as achieving KOOS scores

within the MCID range of population-based normative values (initial gap: OR 2.5 [95% CI 1.3 to 4.7]; $p = 0.006$ and initial stepoff: OR 4.3 [95% CI 1.8 to 10.2]; $p = 0.001$). Postoperative radiographic assessment demonstrated that substantial residual fracture displacement (4 to 6 mm incongruence: OR 3.3 [95% CI 1.7 to 6.5]; $p = < 0.001$ and > 6 mm: OR 5.2 [95% CI 1.7 to 15.8]; $p = 0.004$) and inadequate tibial alignment (MPTA $< 82^\circ$ or $> 92^\circ$: OR 1.5 [95% CI 1.0 to 2.3]; $p = 0.04$ and PPTA $< 4^\circ$ or $> 14^\circ$: OR 1.9 [95% CI 1.3 to 3.0]; $p = 0.003$) were associated with increased odds of not reaching full recovery.

Conclusion In tibial plateau fracture surgery, having a substantial preoperative initial gap > 10 mm or stepoff > 8 mm is associated with an increased odds of not reaching full recovery. In clinical practice, these findings support more informed patient counselling about prognosis. Postoperatively, both residual incongruence > 4 mm (gap and/or stepoff) and inadequate tibial malalignment (MPTA or PPTA) increased these odds, emphasizing the need for meticulous reduction and alignment as well as thoughtful decision-making regarding revision surgery.

INTRODUCTION

Understanding the association between tibial plateau fracture characteristics and functional recovery is critical for guiding patient counseling and managing expectations [17]. Surgeons must consider how specific fracture features, both before and after surgery, relate to long-term outcomes. Currently, available information regarding radiographic measurement provides limited guidance on how initial displacement or residual incongruence and malalignment are associated with recovery, making it challenging to provide prognostic estimates and to guide decision-making regarding revision surgery [1]. Our study addresses this knowledge gap by evaluating the relationship between pre- and postoperative fracture characteristics and patient-reported functional outcomes.

In general, gap (the separation between fracture fragments along the articular surface) and stepoff (the separation of fracture fragments perpendicular to the articular surface) measurements are performed to assess the degree of fracture displacement. These measurements are important indicators when deciding between operative or nonoperative treatment [20, 21]. With operative treatment, the main objectives are to restore articular congruity; achieve normal axial, sagittal, and rotational alignment; as well as to restore knee stability [21, 24, 25]. However, adequate reduction may be technically challenging, and postoperative malreductions are relatively common with more than 30% of surgically treated tibial plateau fractures showing inadequate reduction [14]. Operative results are assessed by measuring this residual articular incongruence, condylar widening, and extraarticular alignment, which is defined as medial proximal tibial angle (MPTA) and posterior proximal tibial angle (PPTA) on postoperative radiographs [4, 5, 10, 26]. These pre- and postoperative measurements are frequently used in daily practice, but the relationship between these measurements and patient-reported functional outcomes remains unclear. Studies have suggested that the severity of the initial fracture displacement and postoperative malalignment are predictors of development of posttraumatic osteoarthritis to a varying extent [9, 12, 26]. However, it remains unknown whether and to what extent patients experience symptoms as a result. Recently, a large multicenter study reported on the association between radiographic measurements and the risk of conversion to TKA after tibial plateau fractures [1]. An important next step would be to assess the association between radiographic measurements and the likelihood of patients reaching full recovery in terms of patient-reported functional outcomes. This is relevant, as many patients may experience some level of disability after their injury, whereas only a few of them eventually undergo conversion to TKA.

Therefore, we asked: (1) What is the association between preoperative fracture displacement (gap and stepoff), as assessed on CT scans, and full recovery in terms of patient-reported outcome (Knee injury and Osteoarthritis Outcome Score [KOOS] scores within the minimum clinically important difference [MCID] range of population-based

normative values)? (2) What is the association between postoperative fracture reduction and knee alignment, as assessed on radiographs, and full recovery in terms of patient-reported outcome?

PATIENTS AND METHODS

Study Design and Setting

We performed a retrospective, cross-sectional, multicenter study including all patients who were surgically treated for a tibial plateau fracture between January 2003 and December 2019 within five trauma centers (three Level 1 trauma centers and two Level 2 trauma centers). The hospitals consisted of one academic center and four nonacademic centers in medium-sized cities in the Netherlands.

Participants

Patients were eligible for inclusion if they were older than 18 years at time of the accident, had available imaging data (preoperative CT scan and postoperative AP and lateral radiographs), were still alive at follow-up, had knowledge of the Dutch language, and had at least 1 year of follow-up. Patients who had nonoperative treatment, complicated fractures leading to amputation, other injuries compromising functional outcome (such as severe concomitant injuries on the same leg or paralysis), or an unknown address at time of follow-up were excluded. A total of 1920 patients were treated for tibial plateau fractures between 2003 and 2019, of which 35% (665 of 1920) had nonoperative treatment, 0.2% (3 of 1920) had primary TKA, 0.2% (4 of 1920) underwent an amputation, 4% (74 of 1920) had preexisting comorbidities of the injured leg, and 3% (53 of 1920) had an unknown address, leaving 58% (1121 of 1920) patients for follow-up analysis. All patients were approached and asked to complete the KOOS questionnaire, of whom 58% (645 of 1121) responded. During the period in question, surgery was generally indicated for fractures with initial displacement or tibial alignment outside normal limits, including an initial gap and/or stepoff > 2 mm, condylar widening (< 0 or > 5 mm), and inadequate tibial alignment (MPTA: < 82° or > 92°, or PPTA: < 4° or > 14°).

Descriptive Data

The mean $\pm$ SD patient age at time of injury was 52 ± 14 years, 68% (436 of 645) of patients were women, and mean follow-up was 7 ± 4 years. The distribution of fracture types was as follows: 4% (26 of 645) Schatzker I, 40% (259 of 645) Schatzker II, 12% (79 of 645) Schatzker III, 11% (68 of 645) Schatzker IV, 10% (66 of 645) Schatzker V, and 23% (147 of 645) Schatzker VI (Table 1).

Table 1 Patient Demographics

Patient characteristics	Total (n = 645)
Age	52 ± 14
Woman	68 (436)
BMI in kg/m ²	26 ± 5
Smoking	122 (144)
Schatzker classification	
I	4 (26)
II	40 (259)
III	12 (79)
IV	11 (68)
V	10 (66)
VI	23 (147)
Fracture characteristics	
Preoperative gap in mm	7 ± 6
Preoperative step-off in mm	8 ± 7
Adequate postoperative condylar widening (0 to 5 mm)	62 (399)
Adequate postoperative incongruence (< 2 mm)	54 (351)
Adequate postoperative MPTA (87° ± 5°)	77 (494)
Adequate postoperative PPTA (9° ± 5°)	75 (482)
Treatment	
Plate osteosynthesis	81 (520)
Screw osteosynthesis	17 (108)
External fixation	2 (12)
Other	1 (5)
Follow-up in years	7 ± 4
Reinterventions during follow-up	
Removal of osteosynthesis material	47 (306)
Reoperation for fracture-related infection	5 (31)
Revision surgery for residual replacement	2 (14)
Reoperation for meniscal or ligamentous repair	2 (16)
Malunion or nonunion	2 (15)
TKA	15 (97)

Data presented as mean ± SD or % and (n).

Patient-reported Outcomes

All eligible patients underwent an informed consent process and provided their consent, were asked to complete the standardized KOOS questionnaire, and were asked whether they underwent conversion to TKA [6]. The KOOS is a validated questionnaire consisting of five subscales: symptoms, pain, activities of daily living (ADL), function in sport and

recreation (sport), and knee-related quality of life (QoL). For each subscale, the normalized score was calculated. The scores of each subscale were calculated by adding individual items (questions) and transforming scores to a range from 0 to 100 (100 indicating no problems and 0 indicating extreme problems). The mean KOOS is defined as the average score of all five KOOS subscales. KOOS scores of patients who had conversion to a TKA should represent the situation as it was before conversion to TKA. This score should indicate the complaints that arose from the initial and residual displacement. Therefore, these patients were assigned an average KOOS score that was reported in a previous cohort of patients with KOOS scores just before conversion to TKA [8]. The assumed KOOS subscores that were assigned to patients who had TKA as their pre-TKA score were 52 for symptoms, 45 for pain, 55 for ADL, 16 for sport, and 27 for QoL. Normative KOOS scores of age-related peers from the general population were used as reference values to determine whether patients had achieved full recovery after tibial plateau fractures [11]. Patients were considered recovered if either their KOOS subscale score or mean KOOS score was equal to or exceeded the average score of age-matched peers from the general population minus the corresponding MCID [11, 16]. All others were classified as not fully recovered. This approach aimed to capture meaningful differences from the patient's perspective while using population-based reference values as a benchmark. The MCID of each KOOS subscale is 12 for mean KOOS, 9 for symptoms, 12 for pain, 10 for ADL, 9 for sports, and 14 for QoL [16].

Pre- and Postoperative Fracture Assessment

All pre- and postoperative images were reassessed, classified according to the Schatzker classification system, and measured through consensus by two observers (TPV, FFAIJ) [23]. Preoperative CT scans were assessed for each patient in the axial, sagittal, and coronal planes, and the maximum gap and stepoff within any of these three planes was determined and reported. The gap was defined as a separation of fracture fragments along the articular surface, and a stepoff was defined as a separation of fracture fragments perpendicular to the articular surface (Fig. 1). The postoperative radiographs were used to evaluate the quality of the fracture reduction and tibial alignment using four radiographic parameters: articular fracture reduction, condylar widening, coronal alignment, and sagittal alignment [1]. Articular fracture reduction was assessed by measuring the maximum residual intraarticular incongruence (the maximum gap and/or stepoff). Condylar widening was assessed by measuring the difference in width between the femoral condyles and the tibial plateau as described by Johannsen et al. [10]. Coronal alignment was assessed by measuring the medial proximal tibial angle (MPTA) on the AP radiograph, and sagittal alignment was assessed by measuring the posterior proximal tibial angle (PPTA) on the lateral radiograph [4, 5]. Fracture reduction was adequate when both gap and/or stepoff were ≤ 2 mm, condylar widening was satisfactory when the difference in width between

the femoral condyles and the tibial plateau was between 0 to 5 mm, coronal alignment was acceptable when the MPTA was $87^\circ \pm 5^\circ$, and sagittal alignment was satisfactory when the PPTA was $9^\circ \pm 5^\circ$ (Fig. 2) [4, 5, 26].

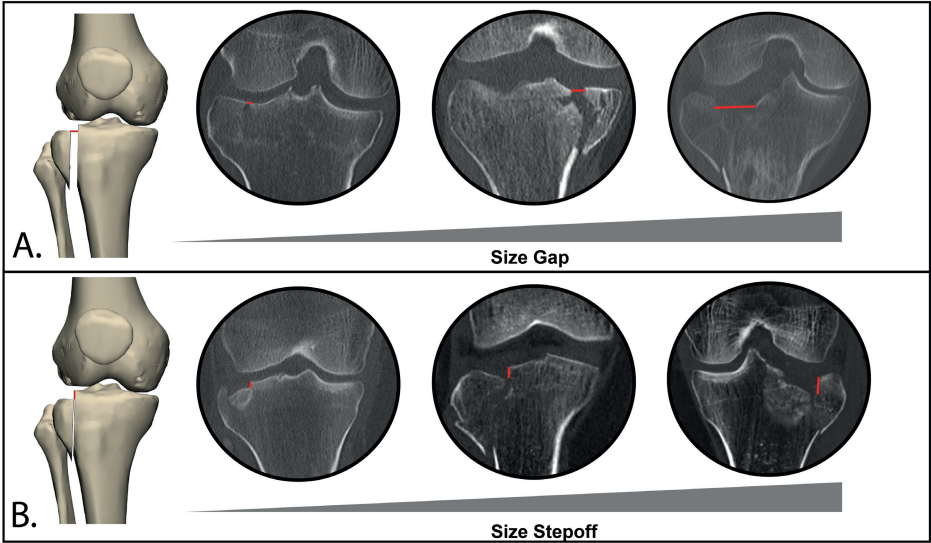


Figure 1 The 3D models show a schematic representation of the (A) preoperative gap and (B) stepoff. The 2D coronal CT images demonstrate actual measurements of (A) increasing initial gaps and (B) stepoffs.

Data Sources

Baseline characteristics were retrieved from the patients' electronic records. The scores from each subscale of the KOOS questionnaire were calculated from the patient survey of the responding patients. Preoperative gap and stepoff measurements were performed on diagnostic CT images. Postoperative incongruity, condylar widening, MPTA, and PPTA measurements were performed on postoperative AP and lateral radiographs.

Primary and Secondary Study Outcomes

The primary goal was to assess the association between the preoperative fracture displacement (gap or stepoff) and recovery in terms of patient-reported functional outcome (KOOS scores within the MCID range of population-based normative values). The secondary goal was to assess the association between the postoperative fracture reduction (incongruity, condylar widening, MPTA, and PPTA) and recovery in terms of patient-reported functional outcome (KOOS scores within the MCID range of population-based normative values).

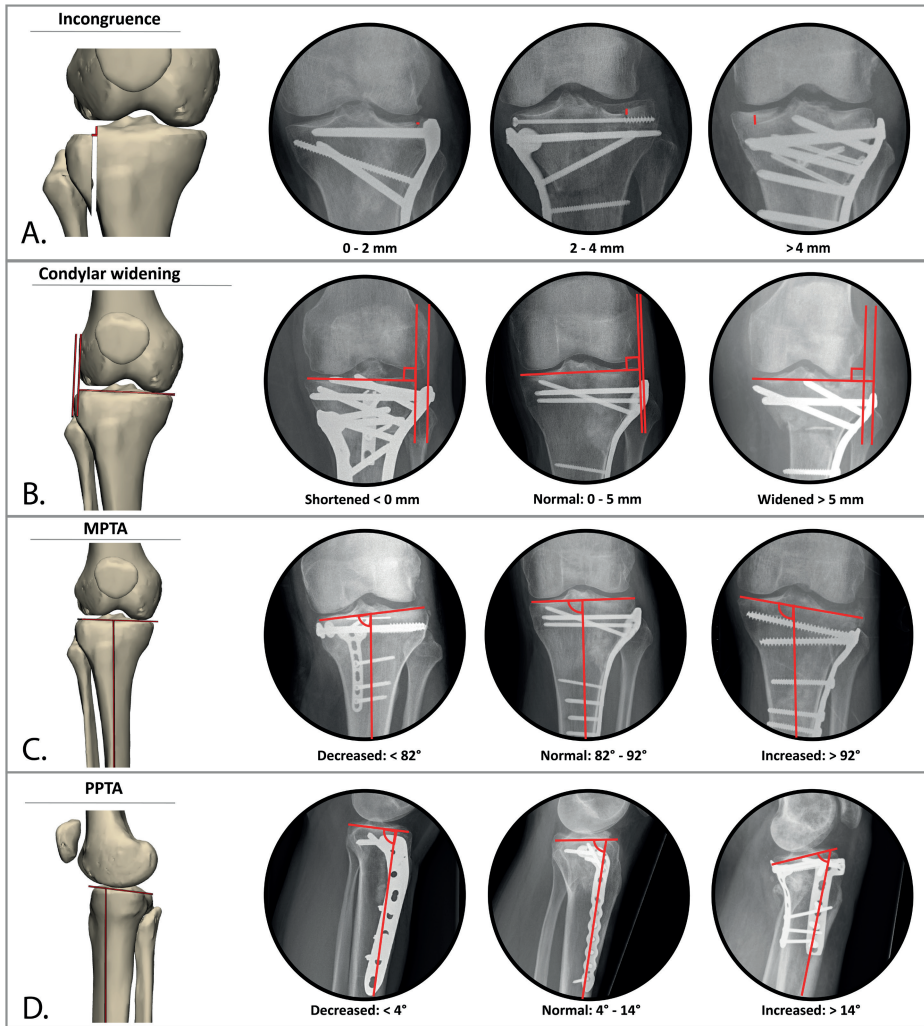


Figure 2 The 3D models show a schematic representation of the residual fracture displacement and tibial alignment: (A) incongruence, (B) condylar widening, (C) MPTA, and (D) PPTA. The 2D coronal CT images demonstrate actual measurements of (A) increasing residual incongruence as well as examples of (B) adequate and inadequate condylar widening, (C) MPTA, and (D) PPTA.

Ethical Approval

We obtained ethical approval for this study from the University Medical Center Groningen, Groningen, the Netherlands (number: 201800411). This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline [28].

Statistical Analysis

We used IBM SPSS software (version 28, IBM Corp) for statistical analysis. We used descriptive statistics to depict the study population. Continuous variables were presented as the mean $\pm$ SD for normally distributed data or median (IQR) for nonnormally distributed data and frequencies were presented as percentage (numerator). First, we assessed the association between the degree of preoperative fracture displacement and patient-reported functional outcome (that is, recovered versus not fully recovered). Therefore, the study population was divided into groups based on the increasing size of the initial gap or stepoff (0 to 2 mm, > 2 to 4 mm, > 4 to 6 mm, > 6 to 8, > 8 to 10 mm and > 10 mm). Binary logistic regression analysis was performed to assess the association between preoperative fracture displacement (gap or stepoff) and whether the patient was considered fully recovered based on their KOOS scores. The models were adjusted for gender, Schatzker classification, BMI (< 18.5 kg/m², 18.5 to 25 kg/m², > 25 kg/m²), complications, postoperative fracture reduction (adequate, defined as incongruence, condylar widening, as well as MPTA and PPTA within normal ranges versus not adequate when outside normal ranges), and follow-up time. Secondly, the association between the degree of postoperative fracture displacement, tibial alignment, and patient-reported functional outcome was assessed (that is, recovered versus not fully recovered). Therefore, the study population was divided into groups based on the size of the residual gap and/or stepoff (0 to 2 mm, > 2 to 4 mm, > 4 to 6 mm, and > 6 mm) or adequate versus inadequate condylar widening, MPTA, or PPTA. Binary logistic regression analysis was performed to assess the association between postoperative fracture reduction (articular incongruence, condylar widening, MPTA, and PPTA) and whether the patient was considered fully recovered according to their KOOS scores. The models were adjusted for gender, Schatzker classification, BMI, complications, and follow-up time. A p value of less than 0.05 was considered to indicate statistical significance.

Analysis of Nonresponders

For the nonresponse analysis, we used the independent samples t-test for continuous variables and the chi-square test for categorical variables. The nonresponse analysis showed that responders to our study survey were slightly older than nonresponders (52 $\pm$ 14 years versus 50 $\pm$ 16 years; $p = 0.001$). Women responded more often (68% [436 of 645] versus 60% [285 of 476]; $p = 0.008$). Knee radiographs and CT images of nonresponders were only available in the initiating center and one affiliated center ($n = 377$) due to data protection and privacy legislation as well as medical ethical reasons. There was no difference in fracture classification between responders and nonresponders (Schatzker I 3% [7 of 228] versus 5% [7 of 149]; Schatzker II 39% [88 of 228] versus 36% [53 of 149]; Schatzker III 11% [24 of 228] versus 7% [10 of 149]; Schatzker IV 12% [28 of 228] versus 16% [24 of 149]; Schatzker V 10% [22 of 228] versus 9%; [13 of 149] Schatzker VI 26% [59 of 228]

versus 28% [42 of 149]; $p = 0.62$). Limited age and gender differences between responders and nonresponders are unlikely to impact results. Moreover, fracture classifications were even similar across groups. Therefore, the findings from responders can reasonably be generalized to all treated patients.

RESULTS

Initial Fracture Displacement

After a mean follow-up of 7 ± 4 years, 45% (290 of 645) of patients had fully recovered (that is, their mean KOOS scores were within the MCID range of population-based normative values). Patients with substantial initial fracture displacement (> 10 mm gap or > 8 mm stepoff) showed an increased odds of not reaching full recovery, regardless of the quality of postoperative fracture reduction (mean KOOS initial gap: OR 2.5 [95% CI 1.3 to 4.7]; $p = 0.006$; mean KOOS initial stepoff: OR 4.3 [95% CI 1.8 to 10.2]; $p = 0.001$) (Table 2). The data on the association between preoperative fracture assessment (gap or stepoff) support the finding that patients with substantial initial fracture displacement (> 10 mm gap or > 8 mm stepoff) had higher odds of not achieving full recovery (Supplemental Tables 1 and 2; <http://links.lww.com/CORR/B474>).

Table 2 Binary logistic regression analysis of the association between preoperative fracture displacement (gap or stepoff^a) and recovery in terms of patient-reported outcome^b

Preoperative Mean KOOS scores			
Measurements	Number of patients	OR (95% CI)	P-value
Gap			
0-2 mm	85		
2-4 mm	155	1.2 (0.7-2.1)	0.63
4-6 mm	124	1.1 (0.6-2.1)	0.72
6-8 mm	75	1.8 (0.9-3.5)	0.11
8-10 mm	53	1.4 (0.6-3.1)	0.42
> 10 mm	153	2.5 (1.3-4.7)	0.006
Stepoff			
0-2 mm	57		
2-4 mm	134	1.3 (0.6-2.5)	0.53
4-6 mm	121	1.5 (0.8-3.1)	0.25
6-8 mm	80	1.8 (0.9-3.9)	0.12
8-10 mm	59	4.3 (1.8-10.2)	0.001
> 10 mm	194	3.0 (1.5-6.0)	0.002

^aThe gap was defined as a separation between fracture fragments along the articular surface, and the stepoff was defined as separation of fracture fragments perpendicular to the articular surface.

^bAdjusted for gender, Schatzker, BMI, complications, postoperative fracture reduction (adequate versus not adequate), and follow-up time. Adequate postoperative fracture reduction is defined as incongruence (gap and/or stepoff) within 0 to 2 mm, condylar widening within 0 to 5 mm, MPTA within $87^\circ \pm 5^\circ$ and PPTA within $9^\circ \pm 5^\circ$.

Residual Fracture Displacement and Tibial Alignment

Patients with substantial residual fracture displacement had increased odds of not reaching full recovery (mean KOOS for 4 to 6 mm incongruence: OR 3.3 [95% CI 1.7 to 6.5]; $p < 0.001$ and for > 6 mm: OR 5.2 [95% CI 1.7 to 15.8]; $p = 0.004$) (Table 3). Condylar widening was not associated with increased odds of not reaching full recovery (mean KOOS: OR 1.3 [95% CI 0.9 to 1.8]; $p = 0.21$). Patients with inadequate postoperative tibial alignment (MPTA and PPTA) had moderately increased odds of not reaching full recovery (mean KOOS for MPTA $< 82^\circ$ or $> 92^\circ$: OR 1.5 [95% CI 1.0 to 2.3]; $p = 0.04$ and for PPTA $< 4^\circ$ or $> 14^\circ$: OR 1.9 [95% CI 1.3 to 3.0]; $p = 0.003$) (Table 3). The data regarding the relationship between postoperative fracture assessment (that is, incongruence, condylar widening, MPTA, and PPTA) and each of the KOOS subscales indicate that both residual incongruence > 4 mm (gap and/or stepoff) and inadequate tibial alignment (MPTA or PPTA) are associated with higher odds of not achieving full recovery (Supplemental Tables 3-6, <http://links.lww.com/CORR/B474>).

Table 3 Binary logistic regression analysis of the association between postoperative fracture displacement, tibial alignment and recovery in terms of patient-reported outcome^a

Postoperative Mean KOOS scores			
Measurements	Number of patients	OR (95% CI)	P-value
Incongruence			
0-2 mm	351		
2-4 mm	198	1.4 (0.9-2.0)	0.10
4-6 mm	65	3.3 (1.7-6.5)	< 0.001
> 6 mm	31	5.2 (1.7-15.8)	0.004
Condylar widening			
Adequate (0-5 mm)	399		
Inadequate (< 0 or > 5 mm)	246	1.3 (0.9-1.8)	0.21
MPTA			
Adequate ($87^\circ \pm 5^\circ$)	494		
Inadequate ($< 82^\circ$ or $> 92^\circ$)	151	1.5 (1.0-2.3)	0.04
PPTA			
Adequate ($9^\circ \pm 5^\circ$)	482		
Inadequate ($< 4^\circ$ or $> 14^\circ$)	163	1.9 (1.3-3.0)	0.003

^aAdjusted for: gender, Schatzker, BMI, complications and follow-up time.

DISCUSSION

We are not aware of studies examining the relationship between radiographic measurements of both initial and residual fracture displacement and their impact on

patient-reported functional outcomes. This lack of data limits surgical decision-making and patient counseling. We present a large, multicenter cohort of surgically treated patients with tibial plateau fractures in which pre- and postoperative radiographic measurements were associated with recovery in terms of patient-reported functional outcome at follow-up. We found that an initial gap > 10 mm or stepoff > 8 mm was associated with increased odds of a patient not reaching full recovery, defined as achieving KOOS scores within the MCID range of population-based normative values. In clinical practice, postoperative radiographs are used to evaluate operative results by measuring the extent of residual fracture displacement (incongruence and condylar widening) as well as tibial alignment (MPTA and PPTA). We demonstrated that patients with substantial residual incongruence (gap and/or stepoff > 4 mm) or inadequate tibial alignment (MPTA or PPTA), had higher odds of not reaching full recovery.

Limitations

This study has several limitations. First, we acknowledge that a retrospective study design is prone to both transfer (nonresponse and loss to follow-up) and selection bias [22]. The response rate was 58% after a mean follow-up of 7 years, which is slightly higher than would be expected according to the evidence on postal survey studies [15]. Although there were some differences in age and gender between responders and nonresponders, fracture classifications were similar, suggesting that it is not likely this affected our results. Nevertheless, it is possible that patients with poorer outcomes were over-represented among nonresponders; if so, the true associations between fracture characteristics and incomplete recovery might be even stronger than reported. Regarding selection bias, our findings are most applicable to surgeons whose training, indications, and experience are quite similar to those in our multicenter cohort. Surgical indications during the study period included substantial initial fracture displacement, condylar widening outside normal limits, or inadequate tibial alignment. The surgeons in our cohort had some variation in clinical experience, reflecting contemporary practice. Second, our findings are applicable for patients with a minimum follow-up of 1 year and should be interpreted with caution for long-term (> 15 years) follow-up. Third, there are some concerns regarding the interobserver reliability of radiographic measurements, despite these measurements remaining in widespread use in clinical practice [2, 7, 13]. We tried to reduce this risk as much as possible by having two observers (TPV, FFAIJ) perform all measurements. Furthermore, a recent study focusing on radiographic factors associated with conversion to TKA showed reasonable intraobserver reliability of tibial plateau fracture measurements (the intraclass correlation coefficients were as follows: gap 0.8, stepoff 0.8, condylar widening 0.8, MPTA 0.7, and PPTA 0.8) [1].

Initial Fracture Displacement

In addition to tibial plateau fracture characteristics and overall injury pattern, surgeons use the degree of preoperative fracture displacement as one of the indications when deciding between operative or nonoperative treatment [3, 17]. Several studies indicated that severity of fracture displacement is predictive for early-onset osteoarthritis [9, 12]. Parkkinen et al. [18] showed that initial fracture displacement exceeding 3.4 mm in the medial plateau was associated with the development of osteoarthritis to a varying extent, but it is still unclear whether and to what extent patients experience symptoms as a result. Our study showed that substantial initial fracture displacement (> 10 mm gap or > 8 mm stepoff) was independently associated with an increased odds of not reaching full recovery (KOOS scores within the MCID range of population-based normative values) in almost all KOOS subscales. Apparently, severe fracture displacement leads to such extensive irreversible damage to the articular surface of the tibial plateau that despite attempts of surgical anatomical reconstructions, it still negatively affects functional recovery. Our findings add to the current knowledge by clarifying to what extent initial fracture displacement is associated with odds of not reaching full recovery. This information can help physicians provide more-informed patient counselling and help them set realistic expectations for prognosis. For example, patients presenting with substantial preoperative displacement (> 10 mm gap or > 8 mm stepoff) can be informed that, despite technically adequate surgery, their odds of full functional recovery are lower, which helps set realistic expectations.

Residual Fracture Displacement and Tibial Alignment

In general, residual fracture displacement < 2 mm after surgery, as measured on postoperative radiographs, is considered adequate fracture reduction [4, 5]. Furthermore, Parkkinen et al. [18, 19] performed some small cohort studies of 41 and 73 patients, respectively; they reported that a residual stepoff > 2 mm, as measured on postoperative radiographs, is associated with the development of certain degree of radiographic posttraumatic osteoarthritis. Our study showed that residual fracture displacement up to 4 mm was not associated with an increased odds of incomplete recovery in a multicenter cohort among 600 patients. However, substantial residual incongruence > 4 mm (gap and/or stepoff) after surgery was associated with increased odds of not reaching full recovery for each of the KOOS subscales during follow-up. Moreover, our study demonstrated that patient recovery relies not only on restoring joint surface congruence but also on ensuring proper tibial alignment. Both inadequate coronal and sagittal alignment (MPTA $< 82^\circ$ or $> 92^\circ$, PPTA $< 4^\circ$ or $> 14^\circ$) after surgery were independently associated with increased odds of not reaching full recovery in most KOOS subscales during follow-up. Studies that assessed the relationship between tibial alignment and PROs are limited. In a cohort of 218 patients with posterior tibial plateau fractures, van den Berg et al. [27] demonstrated that sagittal

malalignment was associated with poorer patient-reported outcomes, emphasizing the importance of reduction and fixation of posterior column fractures. Our findings align with the existing evidence, and furthermore, they contribute to it by demonstrating in a large cohort that encompassed all fracture types to what extent inadequate restoration of coronal and sagittal alignment increases the odds of not reaching full recovery in terms of patient-reported functional outcomes. From a clinical perspective, our findings will raise awareness among surgeons that in tibial plateau fracture surgery, restoring the articular surface is just as crucial as reestablishing coronal and sagittal tibial alignment. For example, after surgery, patients can be informed about the degree of residual incongruence (> 4 mm gap or stepoff) and tibial malalignment (MPTA or PPTA outside normal ranges) to help them understand what this means for their recovery and whether revision surgery might be beneficial.

Conclusion

This large multicenter study on radiographic factors and patient-reported functional outcomes after tibial plateau fracture surgery demonstrated to what extent pre- and postoperative fracture displacement were associated with increased odds of not reaching full recovery in terms of patient-reported outcomes. Patients with substantial preoperative initial fracture displacement (> 10 mm gap or > 8 mm stepoff) are at increased odds of not reaching full recovery due to the severity of the initial damage to tibial plateau, regardless of the quality of postoperative fracture reduction. Moreover, patients with postoperative residual incongruence > 4 mm (gap and/or stepoff) or with inadequate tibial alignment (MPTA $< 82^\circ$ or $> 92^\circ$, PPTA $< 4^\circ$ or $> 14^\circ$), also have increased odds of not reaching full recovery. Future prospective, multicenter cohort studies that comprise patient-reported outcomes at different time-points as well as development of prediction models are needed to clarify the complex relationship between patient factors, fracture characteristics, and clinical outcomes.

REFERENCES

1. Assink N, El Moumni M, Kraeima J, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery: results in a large multicenter cohort. *J Bone Joint Surg Am.* 2023;105:1237-1245.
2. Assink N, Kraeima J, Slump CH, et al. Quantitative 3D measurements of tibial plateau fractures. *Sci Rep.* 2019;9:14395.
3. Assink N, Vaartjes TP, Kramer CJS, et al. What is the patient-reported outcome and complication incidence after operative versus nonoperative treatment of minimally displaced tibial plateau fractures? *Clin Orthop Relat Res.* 2024;482:1744-1752.
4. Barei DP, Nork SE, Mills WJ, Coles CP, Henley MB, Benirschke SK. Functional outcomes of severe bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plates. *J Bone Joint Surg Am.* 2006;88:1713-1721.
5. Barei DP, Nork SE, Mills WJ, Henley MB, Benirschke SK. Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. *J Orthop Trauma.* 2004;18:649-657.
6. de Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of the knee injury and osteoarthritis outcome score: a validation study. *Health Qual Life Outcomes.* 2008;6:1-11.
7. Gordon JE, Chen RC, Dobbs MB, Scott Luhmann SJ, Margaret Rich MM, Schoenecker PL. Interobserver and intraobserver reliability in the evaluation of mechanical axis deviation. *J Pediatr Orthop.* 2009;29:281-284.
8. Heir S, Nerhus TK, R  tterud JH, et al. Focal cartilage defects in the knee impair quality of life as much as severe osteoarthritis: a comparison of knee injury and osteoarthritis outcome score in 4 patient categories scheduled for knee surgery. *Am J Sports Med.* 2010;38:231-237.
9. Jansen H, Frey SP, Dohrt S, Fehske K, Meffert RH. Medium-term results after complex intra-articular fractures of the tibial plateau. *J Orthop Sci.* 2013;18:569-577.
10. Johannsen AM, Cook AM, Gardner MJ, Bishop JA. Defining the width of the normal tibial plateau relative to the distal femur: critical normative data for identifying pathologic widening in tibial plateau fractures. *Clin Anat.* 2018;31:688-692.
11. Larsen P, Rathleff MS, Roos EM, Elsoe R. Knee injury and osteoarthritis outcome score (KOOS)–national record-based reference values. *Knee.* 2023;43:144-152.
12. Manidakis N, Dosani A, Dimitriou R, Stengel D, Matthews S, Giannoudis P. Tibial plateau fractures: functional outcome and incidence of osteoarthritis in 125 cases. *Int Orthop.* 2010;34:565-570.
13. Martin J, Marsh JL, Nepola JV, Dirschl DR, Hurwitz S, De Coster TA. Radiographic fracture assessments: which ones can we reliably make? *J Orthop Trauma.* 2000;14:379-385.
14. Meulenkamp B, Martin R, Desy NM, et al. Incidence, risk factors, and location of articular malreductions of the tibial plateau. *J Orthop Trauma.* 2017;31:146-150.
15. Meyer VM, Benjamins S, El Moumni M, Lange JFM, Pol RA. Global overview of response rates in patient and health care professional surveys in surgery a systematic review. *Ann Surg.* 2022;275:E75-E81.
16. Migliorini F, Maffulli N, Sch  fer L, Simeone F, Bell A, Hofmann UK. Minimal clinically important difference (MCID), substantial clinical benefit (SCB), and patient-acceptable symptom state (PASS) in patients who have undergone total knee arthroplasty: a systematic review. *Knee Surg Relat Res.* 2024;36:3.

17. Molenaars RJ, Mellema JJ, Doornberg JN, Kloen P. Tibial plateau fracture characteristics: computed tomography mapping of lateral, medial, and bicondylar fractures. *J Bone Joint Surg Am.* 2015;97:1512-1520.
18. Parkkinen M, Lindahl J, Mäkinen TJ, Koskinen SK, Mustonen A, Madanat R. Predictors of osteoarthritis following operative treatment of medial tibial plateau fractures. *Injury.* 2018;49:370-375.
19. Parkkinen M, Madanat R, Mustonen A, Koskinen SK, Paavola M, Lindahl J. Factors predicting the development of early osteoarthritis following lateral tibial plateau fractures: mid-term clinical and radiographic outcomes of 73 operatively treated Patients. *Scand J Surg.* 2014;103:256-262.
20. Pelser P. Controversies in the management of tibial plateau fractures. *SA Orthop J.* 2010;9:75-82.
21. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. *EFFORT Open Rev.* 2017;1:225-232.
22. Ramirez-Santana M. Limitations and biases in cohort studies. In: Barría RM, ed. *Cohort Studies in Health Sciences.* InTech; 2018.
23. Schatzker J, McBroom R. The tibial plateau fracture. The Toronto experience 1968-1975. *Clin Orthop Relat Res.* 1979;138:94-104.
24. Timmers TK, van der Ven DJC, de Vries LS, van Olden GDJ. Functional outcome after tibial plateau fracture osteosynthesis: a mean follow-up of 6 years. *Knee.* 2014;21:1210-1215.
25. Tschern H, Lobenhoffer P. Tibia plateau fractures management and expected results. *Clin Orthop Relat Res.* 1993;292:87-100.
26. van den Berg J, De Boer AS, Assink N, et al. Trauma mechanism and patient reported outcome in tibial plateau fractures with posterior involvement. *Knee.* 2021;30:41-50.
27. 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;41:1865-1873.
28. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Int J Surg.* 2014;12: 1495-1499.

APPENDIX

Table 1 Binary logistic regression analysis of the association between preoperative fracture displacement (gap) and recovery in terms of patient-reported outcome^a

Preoperative KOOS scores			
Initial gap	Number of patients	OR (95% CI)	P-value
Symptoms			
0-2 mm	85		
2-4 mm	155	0.9 (0.5-1.7)	0.77
4-6 mm	124	1.1 (0.6-2.1)	0.74
6-8 mm	75	1.6 (0.8-3.3)	0.17
8-10 mm	53	1.5 (0.7-3.4)	0.29
> 10 mm	153	2.7 (1.4-5.3)	0.002
Pain			
0-2 mm	85		
2-4 mm	155	1.7 (0.9-3.1)	0.09
4-6 mm	124	1.1 (0.6-2.2)	0.72
6-8 mm	75	1.8 (0.9-3.6)	0.11
8-10 mm	53	2.0 (0.9-4.4)	0.10
> 10 mm	153	2.1 (1.1-4.1)	0.03
Activities of daily living			
0-2 mm	85		
2-4 mm	155	1.5 (0.8-2.7)	0.21
4-6 mm	124	1.2 (0.6-2.2)	0.67
6-8 mm	75	2.0 (1.0-4.1)	0.06
8-10 mm	53	1.6 (0.7-3.6)	0.25
> 10 mm	153	2.0 (1.0-3.9)	0.04
Sport			
0-2 mm	85		
2-4 mm	155	1.2 (0.7-2.2)	0.51
4-6 mm	124	1.2 (0.6-2.3)	0.54
6-8 mm	75	1.5 (0.7-3.1)	0.26
8-10 mm	53	1.1 (0.5-2.6)	0.75
> 10 mm	153	3.8 (1.8-8.0)	< 0.001
Quality of life			
0-2 mm	85		
2-4 mm	155	0.9 (0.5-1.5)	0.64
4-6 mm	124	0.8 (0.4-1.4)	0.39
6-8 mm	75	1.2 (0.6-2.4)	0.57
8-10 mm	53	1.4 (0.6-3.0)	0.47
> 10 mm	153	1.7 (0.7-3.2)	0.10
Mean			
0-2 mm	85		
2-4 mm	155	1.2 (0.7-2.1)	0.63
4-6 mm	124	1.1 (0.6-2.1)	0.72
6-8 mm	75	1.8 (0.9-3.5)	0.11
8-10 mm	53	1.4 (0.6-3.1)	0.42
> 10 mm	153	2.5 (1.3-4.7)	0.006

^aAdjusted for gender, Schatzker, BMI, complications, postoperative fracture reduction (adequate versus not adequate), and follow-up time. Adequate postoperative fracture reduction is defined as incongruence (gap and/or stepoff) within 0 to 2 mm, condylar widening within 0 to 5 mm, MPTA within $87^\circ \pm 5^\circ$ and PPTA within $9^\circ \pm 5^\circ$.

Table 2 Binary logistic regression analysis of the association between preoperative fracture displacement (stepoff) and recovery in terms of patient-reported outcome^a

Preoperative KOOS scores			
Initial stepoff	Number of patients	OR (95% CI)	P-value
Symptoms			
0-2 mm	57		
2-4 mm	134	1.0 (0.5-2.1)	0.94
4-6 mm	121	1.1 (0.6-2.3)	0.74
6-8 mm	80	1.3 (0.6-2.9)	0.47
8-10 mm	59	2.8 (1.2-6.6)	0.02
> 10 mm	194	2.9 (1.4-5.8)	0.003
Pain			
0-2 mm	57		
2-4 mm	134	1.3 (0.6-2.6)	0.50
4-6 mm	121	1.1 (0.6-2.3)	0.74
6-8 mm	80	1.4 (0.7-3.0)	0.40
8-10 mm	59	2.5 (1.1-5.7)	0.04
> 10 mm	194	2.3 (1.2-4.6)	0.02
Activities of daily living			
0-2 mm	57		
2-4 mm	134	1.2 (0.6-2.3)	0.71
4-6 mm	121	1.0 (0.5-2.1)	0.99
6-8 mm	80	1.6 (0.8-3.6)	0.21
8-10 mm	59	2.4 (1.0-5.6)	0.04
> 10 mm	194	2.0 (1.0-3.9)	0.060
Sport			
0-2 mm	57		
2-4 mm	134	0.9 (0.5-1.8)	0.80
4-6 mm	121	1.0 (0.5-2.1)	0.96
6-8 mm	80	1.2 (0.5-2.5)	0.72
8-10 mm	59	2.6 (1.0-6.6)	0.06
> 10 mm	194	2.3 (1.1-4.7)	0.03
Quality of life			
0-2 mm	57		
2-4 mm	134	1.7 (0.9-3.4)	0.11
4-6 mm	121	1.9 (1.0-3.8)	0.07
6-8 mm	80	1.9 (0.9-4.0)	0.10
8-10 mm	59	3.3 (1.4-7.6)	0.006
> 10 mm	194	3.2 (1.6-6.3)	< 0.001
Mean			
0-2 mm	57		
2-4 mm	134	1.3 (0.6-2.5)	0.53
4-6 mm	121	1.5 (0.8-3.1)	0.25
6-8 mm	80	1.8 (0.9-3.9)	0.12
8-10 mm	59	4.3 (1.8-10.2)	0.001
> 10 mm	194	3.0 (1.5-6.0)	0.002

^aAdjusted for gender, Schatzker, BMI, complications, postoperative fracture reduction (adequate versus not adequate), and follow-up time. Adequate postoperative fracture reduction is defined as incongruence (gap and/or stepoff) within 0 to 2 mm, condylar widening within 0 to 5 mm, MPFA within $87^\circ \pm 5^\circ$ and PPTA within $9^\circ \pm 5^\circ$.

Table 3 Binary logistic regression analysis of the association between postoperative fracture displacement (incongruence) and recovery in terms of patient-reported outcome^a

Postoperative KOOS scores			
Residual incongruence	Number of patients	OR (95% CI)	P-value
Symptoms			
0-2 mm	351		
2-4 mm	198	1.4 (1.0-2.0)	0.09
4-6 mm	65	2.6 (1.4-4.9)	0.003
> 6 mm	31	8.9 (2.6-30.7)	< 0.001
Pain			
0-2 mm	351		
2-4 mm	198	1.0 (0.7-1.4)	0.93
4-6 mm	65	2.2 (1.2-4.0)	0.01
> 6 mm	31	7.6 (2.5-23.0)	< 0.001
Activities of daily living			
0-2 mm	351		
2-4 mm	198	0.9 (0.6-1.3)	0.89
4-6 mm	65	2.2 (1.2-4.1)	0.01
> 6 mm	31	4.1 (1.6-10.8)	0.004
Sport			
0-2 mm	351		
2-4 mm	198	1.4 (0.9-2.1)	0.13
4-6 mm	65	2.3 (1.1-5.1)	0.04
> 6 mm	31	11.8 (1.6-90.0)	0.02
Quality of life			
0-2 mm	351		
2-4 mm	198	1.3 (0.9-1.9)	0.16
4-6 mm	65	2.1 (1.1-4.0)	0.03
> 6 mm	31	5.7 (1.7-19.9)	0.006
Mean			
0-2 mm	351		
2-4 mm	198	1.4 (0.9-2.0)	0.10
4-6 mm	65	3.3 (1.7-6.5)	< 0.001
> 6 mm	31	5.2 (1.7-15.8)	0.004

^aAdjusted for gender, Schatzker, BMI, complications and follow-up time.

Table 4 Binary logistic regression analysis of the association between postoperative fracture displacement (condylar widening) and recovery in terms of patient-reported outcome^a

Postoperative KOOS scores			
Condylar widening ^b	Number of patients	OR (95% CI)	P-value
Symptoms			
Adequate	399		
Inadequate	246	1.2 (0.9-1.7)	0.29
Pain			
Adequate	399		
Inadequate	246	1.3 (0.9-1.9)	0.13
Activities of daily living			
Adequate	399		
Inadequate	246	1.1 (0.8-1.6)	0.55
Sport			
Adequate	399		
Inadequate	246	1.0 (0.7-1.5)	0.93
Quality of life			
Adequate	399		
Inadequate	246	1.0 (0.7-1.5)	0.85
Mean			
Adequate	399		
Inadequate	246	1.3 (0.9-1.8)	0.21

^aAdjusted for gender, Schatzker, BMI, complications and follow-up duration.^bAdequate condylar widening (0-5 mm), inadequate condylar widening (< 0 or > 5 mm).

Table 5 Binary logistic regression analysis of the association between postoperative fracture displacement (MPTA) and recovery in terms of patient-reported outcome^a

Postoperative KOOS scores			
Tibial alignment (MPTA^b)	Number of patients	OR (95% CI)	P-value
Symptoms			
Adequate	494		
Inadequate	151	1.5 (1.0-2.2)	0.07
Pain			
Adequate	494		
Inadequate	151	1.5 (1.0-2.3)	0.04
Activities of daily living			
Adequate	494		
Inadequate	151	1.5 (1.0-2.3)	0.04
Sport			
Adequate	494		
Inadequate	151	1.4 (0.9-2.3)	0.16
Quality of life			
Adequate	494		
Inadequate	151	1.5 (1.0-2.3)	0.07
Mean			
Adequate	494		
Inadequate	151	1.5 (1.0-2.3)	0.04

^aAdjusted for gender, Schatzker, BMI, complications and follow-up time.

^bAdequate MPTA ($87^\circ \pm 5^\circ$), inadequate MPTA ($< 82^\circ$ or $> 92^\circ$).

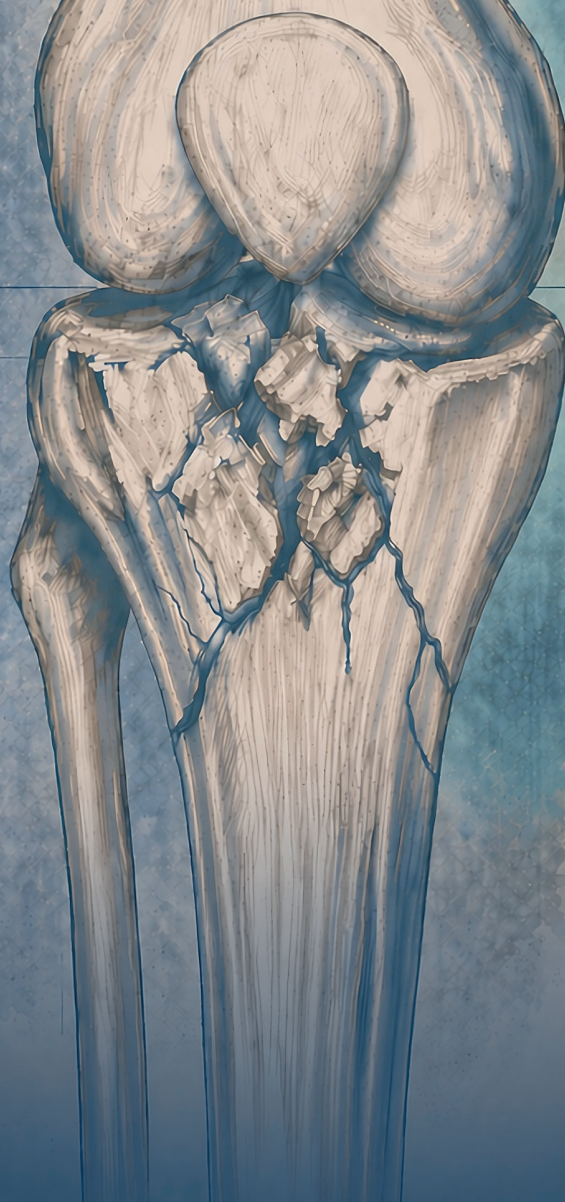
Table 6 Binary logistic regression analysis of the association between postoperative fracture displacement (PPTA) and recovery in terms of patient-reported outcome^a

Postoperative KOOS scores			
Tibial alignment (PPTA ^b)	Number of patients	OR (95% CI)	P-value
Symptoms			
Adequate	482		
Inadequate	163	1.7 (1.1-2.6)	0.01
Pain			
Adequate	482		
Inadequate	163	2.0 (1.3-3.0)	0.001
Activities of daily living			
Adequate	482		
Inadequate	163	2.2 (1.4-3.3)	< 0.001
Sport			
Adequate	482		
Inadequate	163	1.5 (0.9-2.4)	0.13
Quality of life			
Adequate	482		
Inadequate	163	1.5 (1.0-2.4)	0.06
Mean			
Adequate	482		
Inadequate	163	1.9 (1.3-3.0)	0.003

^aAdjusted for gender, Schatzker, BMI, complications and follow-up time.^bAdequate PPTA (9° ± 5°), inadequate PPTA (< 4° or > 14°).

TIBIAL PLATEAU
FRACTURE

ANTERIOR VIEW



PART III

How do they recover

Chapter 7



Most patients with tibial plateau fractures regain function for daily activities but do not return to their pre-injury level of sport: comparison of multicenter cohort of 1101 patients and age-related peers

Thijs P. Vaartjes, Fabian J. van der Sluis, Eelke Bosma,
Joost G. ten Brinke, Reinier de Groot, Job N. Doornberg,
Harm Hoekstra, Frank F.A. IJpma, Nick Assink

This chapter was published in:
European Journal of Trauma and Emergency Surgery (2025) 51:285
DOI 10.1007/s00068-025-02958-9

ABSTRACT

Purpose The aim was to evaluate patient-reported outcomes - symptoms, pain, activities of daily living (ADL), sports, and quality of life (QoL) - in patients with tibial plateau fractures. Outcomes were compared with those of age-matched peers from the general population to support patient counseling.

Methods A multicenter cross-sectional study was performed including 1101 patients with tibial plateau fractures between 2003 and 2019. At mean follow-up of 6 ± 4 years, patients completed the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire. Patients were grouped by age, treatment, and Schatzker classification. Summery Independent-Samples t-tests were used to compare patients KOOS values with age-related peers reference values. Descriptive statistics were used to report the proportion of patients who recovered within the minimal clinically important difference (MCID) range.

Results Nonoperatively treated patients scored 5% lower than age-related peers for symptoms, pain and ADL. These differences did not exceed the MCID, and 68% of patients regained the level of age-related peers. Patients < 60 years scored 22% lower for sports and QoL, with 45% and 53% of patients to peer levels. Operatively treated patients scored 14% lower compared to age-related peers for symptoms, pain and ADL, exceeding the MCID, and 53% of patients regained the level of peers. For sports and QoL, scores were 36% lower, with only 30%, and 39% of patients returning to peer levels.

Conclusion While most patients regain satisfactory function in daily activities after tibial plateau fractures, many—especially those treated operatively—do not return to pre-injury levels of sports and QoL. Our findings provide a guideline for managing patients' expectations among different age-groups.

INTRODUCTION

Tibial plateau fractures account for 1–2% of all fractures and are intra-articular fractures that are challenging to treat [1, 2]. Since the tibial plateau is among the most loadbearing areas in the body, these fractures can have a major impact on patient's life. At short term these injuries are mainly disabling due to immobilization or postoperative recovery. In the long term, these patients are at higher risks of post-traumatic osteoarthritis, chronic pain, knee stiffness or instability, which may ultimately result in the conversion to a total knee arthroplasty (TKA) [3–7]. Studies reporting on patient-reported functional outcome after tibial plateau fractures have shown contradictory results. While some studies report satisfactory outcomes during follow-up, others highlight poorer outcomes after both operative and nonoperative treatment [8–13].

Although functional outcomes after tibial plateau fractures have been studied extensively, it remains unclear how well patients recover over time and whether their outcomes match those of age-matched peers in the general population. Recently, van den Berg et al. compared functional outcomes of patients with tibial plateau fractures with reference values of the general population [10]. They reported that outcomes after both operative and nonoperative treatment were significantly lower compared to those of the reference population. Similar results were observed in the study by Timmer et al. who reported fair functional outcomes in surgically treated patients, although these were lower compared to the general Dutch population [8]. However, these studies compared patient-reported functional outcomes of the whole study population without accounting for the patient's age and fracture types. Literature on population-based reference values for functional outcome scores indicate that functional outcomes vary across different age groups within the general population [14, 15]. This could be due to differences in level of activity, ambulatory status, preexisting comorbidities, and coping mechanisms between younger and older individuals. To adequately counsel patients during treatment it is important to understand to what extent they will recover during follow-up and how their outcomes compare to those of age-related peers in the general population.

In this study, we aim to assess the differences in functional outcome after tibial plateau fractures compared with those of the age-related general population. Assuming that healthy peers from the general population represents the pre-injury status, every patient wants to know to what extent they will recovery relative to this healthy baseline. Also, younger patients often have different levels of physical functioning and expectations compared to older patients, highlighting the importance of assessing outcomes across different age groups. The goal of this study is to provide a guideline for patient counselling by describing functional outcomes following tibial plateau fractures in relation to healthy peers, stratified by age group and fracture type. This information could be helpful to manage patient's expectations more accurately. Therefore, we posed the following

research question: How do patient-reported outcomes regarding knee symptoms, pain, daily activities, sports and quality of life differ between patients who sustained a tibial plateau fracture and age-related peers from the general population?

METHODS

Study design

A multicenter cross-sectional study was performed on all patients treated for a tibial plateau fracture in the orthopaedic or trauma surgery department of six trauma centers in two countries (University Medical Center Groningen, Isala hospitals, Gelre hospitals, Martini hospital, Medical Spectrum Twente and KU Leuven University Hospitals) between January 2003 and December 2019. Patients were eligible for inclusion if they had a preoperative CT scan available, had knowledge of the Dutch language, were alive at the time of follow-up and had at least one year follow-up. Patients < 18 years of age at time of the accident, with compromising injuries (e.g. severe concomitant injuries on the same leg or paralysis), complicated fractures requiring amputation or had an unknown address at time of follow-up were excluded. Baseline characteristics were retrieved from the patients' electronic records. Knee radiographs and CT images taken within 2 weeks after the patient's injury were reassessed and classified through consensus by two observers (TPV, FFAIJ) with experience in tibial plateau fracture management according to the Schatzker classification systems [16]. All eligible patients were approached by posted mail and asked for written informed consent and to complete the validated patient-reported outcome measures. The study procedure was approved by the institutional review board of all participating centers (number: 201800411) and was performed in accordance with the relevant guidelines and regulations. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline [17].

Patient-reported outcomes

All responding patients completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire [18]. The validated and standardized KOOS questionnaire consists of five subscales: symptoms, pain, activities of daily living (ADL), function in sports and recreation (sport), and knee-related quality of life (QoL). The total score was calculated for each subscale by adding the scores of individual items (i.e. questions) and transforming them to a range from 0 to 100, with higher scores indicating better function. In addition, patients were asked whether they underwent conversion to TKA. Patients with conversion to TKA were assigned an average KOOS score based on a previously reported cohort of patients' KOOS scores measured just before conversion to TKA [19]. The reported KOOS

scores of each subscale were 52 for symptoms, 45 for pain, 55 for ADL, 16 for sport and 27 for QoL. The minimal clinically important difference (MCID) of each subscale from the KOOS questionnaire is 9 for symptoms, 12 for pain, 10 for ADL, 9 for sports, and 14 for QoL [20]. Functional outcomes of age-related peers were retrieved from a previous cohort that described National record-based reference values for the KOOS questionnaire of the general population in Denmark [15].

Statistical analysis

IBM SPSS software, version 23.0 for Windows (IBM Corporation, Chicago, IL, USA) was used for statistical analysis and figures were created with Microsoft Excel 365 (Version 2025, Microsoft Corporation, Redmond, WA, USA). Continuous variables are presented as the mean and standard deviation (SD) for normally distributed data, and median and inter-quartile range (IQR) for nonnormally distributed data. Descriptive statistics were used to describe the study population. The study population was divided into six groups based on age (18–29, 30–39, 40–49, 50–59, 60–69 and 70+). Analysis of variance (ANOVA) was applied to compare continuous variables, while the chi-square test was used for categorical variables to assess differences in patient and fracture characteristics across age groups. The study population was further divided based on treatment (operative or nonoperative) and a Summery Independent-Samples t-test was used to assess differences in patient-reported functional outcome between patients and age-related peers. Descriptive statistics were used to describe the number of patients who had recovered after operative or nonoperative treatment, defined as having KOOS-score within the MCID range of age-related peers [15]. For sub-analysis the study population was divided based on age and fracture classification according to Schatzker [16]. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Between 2003 and 2019, a total of 2288 patients were treated for a tibial plateau fracture within six hospitals. Of these patients, 144 were < 18 years, 89 had compromising injuries, 4 had an amputation and 60 had an unknown address, leaving 1991 patients eligible for follow-up analysis. A total of 55% (1101 of 1991) of patients responded to the questionnaire and were included in the study. The mean age at the time of injury was 53 ± 15 years, 68% (751 of 1101) of patients were female, and the mean follow up was 6 ± 4 years. A total of 756 out of 1101 (69%) patients were treated operatively by using plate and/or screw osteosynthesis. Eventually, 123 (11%) patients underwent conversion to TKA during follow-up (Table 1). Non-response analysis demonstrated that non-responders were slightly younger (51 ± 17 vs. 53 ± 15 , $p = < 0.001$), less often female (58% vs. 68%, $p = < 0.001$), and less often treated surgically (57% vs. 69%, $p = < 0.001$) in comparison with

responders. There was no difference in fracture classification between responders and non-responders (Schatzker I 3% versus 5%; Schatzker II 39% versus 36%; Schatzker III 11% versus 7%; Schatzker IV 12% versus 16%; Schatzker V 10% versus 9%; Schatzker VI 26% versus 28% $p = 0.618$).

Table 1 Demographics

Age group	18-29	30-39	40-49	50-59	60-69	70+	P-value
Number of patients	105	102	158	329	279	128	
Age (years)	24 ± 3	35 ± 3	45 ± 3	55 ± 3	64 ± 3	75 ± 5	0.000
Sex (Female)	56 (53%)	48 (47%)	85 (54%)	232 (71%)	219 (79%)	111 (87%)	<0.001
Body Mass Index	25 ± 6	26 ± 5	28 ± 5	27 ± 4	26 ± 4	26 ± 4	<0.001
Smoking	29 (28%)	30 (30%)	43 (27%)	72 (22%)	40 (15%)	6 (5%)	<0.001
Diabetic	3 (3%)	4 (4%)	9 (6%)	27 (8%)	31 (11%)	12 (10%)	0.036
Treatment							0.084
Operative	70 (67%)	76 (75%)	113 (72%)	236 (72%)	185 (66%)	76 (59%)	
Nonoperative	35 (33%)	26 (26%)	45 (29%)	93 (28%)	94 (34%)	52 (41%)	
Trauma mechanism							<0.001
Low energy trauma	80 (80%)	85 (85%)	124 (82%)	282 (88%)	252 (93%)	120 (95%)	
High energy trauma	20 (20%)	15 (15%)	27 (18%)	37 (12%)	18 (7%)	6 (5%)	
Fracture classification							0.001
Schatzker I	14 (13%)	10 (10%)	13 (8%)	21 (6%)	11 (4%)	8 (6%)	
Schatzker II	36 (34%)	26 (26%)	58 (37%)	114 (35%)	105 (38%)	45 (35%)	
Schatzker III	24 (23%)	28 (28%)	26 (17%)	72 (22%)	67 (24%)	33 (26%)	
Schatzker IV	12 (11%)	24 (24%)	29 (18%)	37 (11%)	36 (13%)	20 (16%)	
Schatzker V	13 (12%)	4 (4%)	10 (6%)	28 (9%)	12 (4%)	6 (5%)	
Schatzker VI	6 (6%)	10 (10%)	22 (14%)	57 (17%)	48 (17%)	16 (13%)	
Gap (mm)	5.0 ± 5.7	5.4 ± 6.0	5.1 ± 4.8	5.9 ± 6.1	5.1 ± 5.3	5.4 ± 5.2	0.552
Step-off (mm)	5.6 ± 6.4	6.2 ± 6.5	5.8 ± 5.2	6.8 ± 6.7	5.7 ± 5.5	6.2 ± 6.4	0.257
Follow-up (years)	7 ± 4	8 ± 5	7 ± 4	6 ± 4	6 ± 4	5 ± 3	<0.001
Conversion to TKA	0 (0%)	4 (4%)	9 (6%)	40 (12%)	44 (16%)	26 (20%)	<0.001

Numbers are presented as mean ± standard deviation or as number and percentage.

Level of recovery as compared to age-related peers

The average KOOS-scores were lower in most subscales for both operatively and nonoperatively treated patients with tibial plateau fractures as compared to their age-related peers from the general population (Fig. 1).

Nonoperatively treated patients scored 5% lower for the subscales symptoms, pain and ADL, but these differences did not exceed the minimal clinical important difference (MCID)

(Table 2). For these same subscales, 60–81% of patient recovered well and reached the level of age- related peers within the MCID range (Table 2). For the subscales sports and recreation as well as quality of life, patients younger than 60 years scored 22% lower compared to peers from the general population, with differences exceeding the MCID in these younger age groups. For sports and recreation, only 41–49% of the younger patients (< 60 years) and for quality of life only 49–58% of younger patients reached the level of age-related peers within the MCID range (Table 2).

Operative treated patients scored 14% lower than peers on the symptoms, pain and ADL subscales. In most age groups, the scores slightly exceeded the minimal clinical important difference (MCID) (Table 3). For these subscales, 43–67% of patients recovered well and reached the level of age-related peers within the MCID range (Table 3). For the sports and recreation as well as quality of life, scores were substantially lower, by approximately 36% compared to peers, and these differences exceeded the MCID across all age groups. For sports and recreation, and quality of life, 26–35% and 28–47% of patients reached the level of age- related peers within the MCID range, respectively (Table 3). After tibial plateau fractures, sports and recreation as well as quality of life were the most affected, which is particularly pronounced in younger age groups (Tables 2 and 3). Having established a general understanding of how patients in specific age categories perform compared to their age-related peers, it is important to recognize that fracture complexity varies within these age and treatment groups. Table 1 in the supplementary data presents patient functioning stratified by Schatzker classification, compared to age related peers. Overall, higher Schatzker classifications, which reflect more severe fractures, are associated with lower expected functional recovery (Fig. 1 appendix).

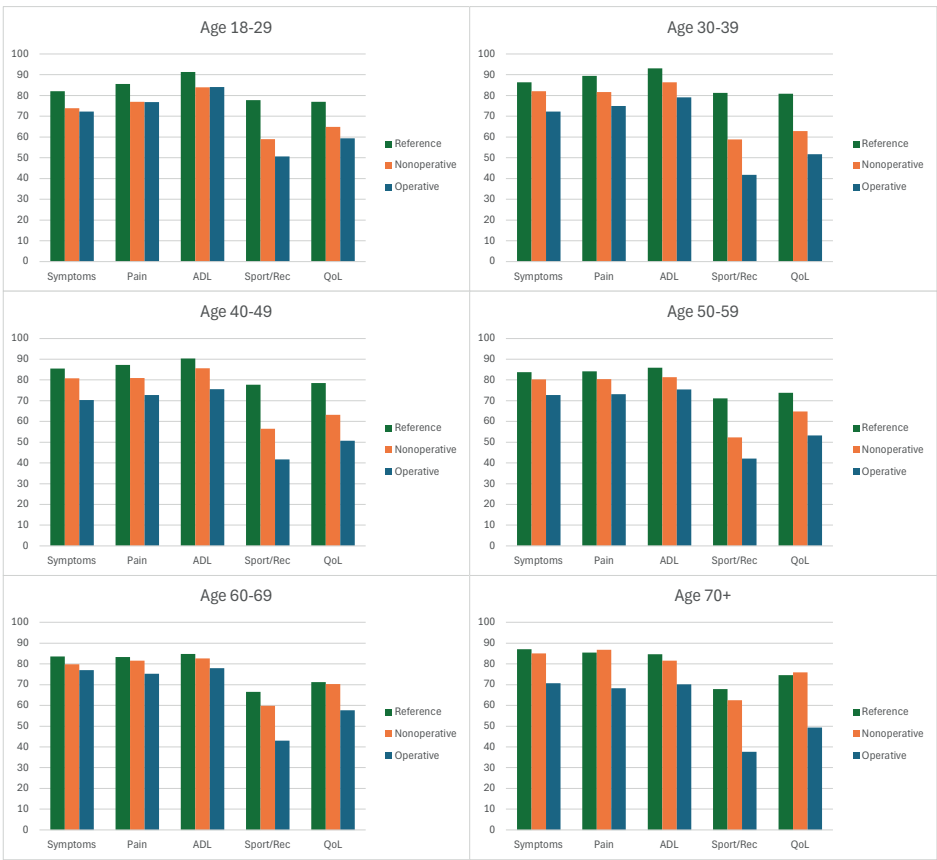


Figure 1 The average KOOS-score for each subscale of the different age and treatment groups compared with age-related peers.

Table 2 The average KOOS-score of each age group after nonoperative treatment compared with age-related peers

Nonoperative	Outcome score after Tibial plateau fracture		Outcome score general population			Difference on a scale of 0-100	
Age group	Number of patients	KOOS Symptoms*	Number of peers	KOOS Symptoms*	P-value	MCID 9**	Number of recovered patients ***
18-29	35	73.8 ± 21.7	153	82.0 ± 18.1	0.021	-8.2	21 (60%)
30-39	26	82.1 ± 16.8	218	86.3 ± 14.7	0.176	-4.2	17 (65%)
40-49	45	80.8 ± 15.2	351	85.5 ± 16.3	0.067	-4.7	28 (62%)
50-59	93	80.2 ± 19.2	473	83.7 ± 17.3	0.081	-3.5	62 (67%)
60-69	93	79.8 ± 21.1	640	83.6 ± 17.3	0.100	-3.8	62 (66%)
70+	52	85.0 ± 19.7	1007	87.0 ± 16.2	0.391	-2.0	41 (79%)
Age group	Number of patients	KOOS Pain*	Number of peers	KOOS Pain*	P-value	MCID 12 **	Number of recovered patients ***
18-29	35	76.9 ± 20.3	153	85.6 ± 18.2	0.013	-8.7	22 (63%)
30-39	26	81.7 ± 18.9	218	89.4 ± 15.3	0.019	-7.7	18 (69%)
40-49	45	80.9 ± 19.3	351	87.2 ± 17.1	0.022	-6.3	27 (60%)
50-59	93	80.4 ± 22.5	473	84.2 ± 19.0	0.088	-3.8	64 (69%)
60-69	92	81.5 ± 21.8	640	83.3 ± 19.3	0.411	-1.8	65 (71%)
70+	52	86.8 ± 19.2	1004	85.4 ± 18.0	0.586	+1.4	42 (81%)
Age group	Number of patients	KOOS ADL*	Number of peers	KOOS ADL*	P-value	MCID 10 **	Number of recovered patients ***
18-29	35	83.9 ± 19.5	152	91.3 ± 14.1	0.040	-7.4	24 (69%)
30-39	26	86.4 ± 18.3	217	93.0 ± 12.5	0.084	-6.6	18 (69%)
40-49	45	85.6 ± 16.7	350	90.4 ± 15.3	0.051	-4.8	30 (67%)
50-59	93	81.3 ± 20.9	473	85.9 ± 18.4	0.050	-4.6	62 (67%)
60-69	93	82.6 ± 20.0	639	84.8 ± 18.1	0.280	-2.2	63 (68%)
70+	52	81.5 ± 26.6	998	84.7 ± 18.1	0.395	-3.3	39 (75%)
Age group	Number of patients	KOOS Sport*	Number of peers	KOOS Sport*	P-value	MCID 9 **	Number of recovered patients ***
18-29	35	58.9 ± 33.4	152	77.8 ± 27.1	0.003	-18.9	17 (49%)
30-39	25	58.8 ± 38.4	217	81.2 ± 25.1	0.008	-22.4	12 (48%)
40-49	45	56.5 ± 34.1	348	77.7 ± 27.3	<0.001	-21.2	19 (42%)
50-59	91	52.3 ± 35.7	469	71.1 ± 29.9	<0.001	-18.8	37 (41%)
60-69	88	59.8 ± 33.0	631	66.5 ± 31.4	0.063	-6.7	50 (57%)
70+	43	62.5 ± 36.8	982	67.8 ± 31.2	0.280	-5.3	27 (63%)
Age group	Number of patients	KOOS Quality of life*	Number of peers	KOOS Quality of life*	P-value	MCID 14 **	Number of recovered patients ***
18-29	35	64.9 ± 24.6	152	76.9 ± 25.0	0.011	-12.0	18 (51%)
30-39	25	62.8 ± 24.4	217	80.8 ± 23.2	<0.001	-18.0	13 (52%)
40-49	45	63.2 ± 27.3	351	78.5 ± 23.0	<0.001	-15.3	22 (49%)
50-59	93	64.8 ± 27.6	473	73.8 ± 25.9	0.003	-9.0	54 (58%)
60-69	93	70.3 ± 27.3	640	71.2 ± 26.4	0.760	-0.9	61 (66%)
70+	51	75.9 ± 28.6	996	74.6 ± 25.6	0.725	+1.3	38 (75%)

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Table 3 The average KOOS-score of each age group after operative treatment compared with age-related peers

Operative	Outcome score after Tibial plateau fracture		Outcome score general population		Difference on a scale of 0-100		
Age group	Number of patients	KOOS Symptoms*	Number of peers	KOOS Symptoms*	P-value	MCID 9**	Number of recovered patients ***
18-29	70	72.3 ± 20.4	153	82.0 ± 18.1	<0.001	-9.7	37 (53%)
30-39	76	72.4 ± 21.9	218	86.3 ± 14.7	<0.001	-13.9	34 (45%)
40-49	113	70.3 ± 22.1	351	85.5 ± 16.3	<0.001	-15.2	52 (46%)
50-59	236	72.7 ± 21.8	473	83.7 ± 17.3	<0.001	-11.0	119 (50%)
60-69	184	77.0 ± 19.3	640	83.6 ± 17.3	<0.001	-6.6	109 (59%)
70+	75	70.6 ± 22.7	1007	87.0 ± 16.2	<0.001	-16.3	32 (43%)
Age group	Number of patients	KOOS Pain*	Number of peers	KOOS Pain*	P-value	MCID 12 **	Number of recovered patients ***
18-29	70	76.8 ± 20.0	153	85.6 ± 18.2	0.001	-8.8	42 (60%)
30-39	76	74.9 ± 23.2	218	89.4 ± 15.3	<0.001	-14.5	43 (57%)
40-49	113	72.7 ± 22.6	351	87.2 ± 17.1	<0.001	-14.5	56 (50%)
50-59	236	73.2 ± 23.8	473	84.2 ± 19.0	<0.001	-11.0	133 (56%)
60-69	184	75.2 ± 22.2	640	83.3 ± 19.3	<0.001	-8.1	108 (59%)
70+	75	68.3 ± 25.3	1004	85.4 ± 18.0	<0.001	-17.0	34 (45%)
Age group	Number of patients	KOOS ADL*	Number of peers	KOOS ADL*	P-value	MCID 10 **	Number of recovered patients ***
18-29	70	84.1 ± 18.2	152	91.3 ± 14.1	0.004	-7.2	47 (67%)
30-39	76	79.1 ± 22.4	217	93.0 ± 12.5	<0.001	-13.9	45 (59%)
40-49	113	75.5 ± 20.4	350	90.4 ± 15.3	<0.001	-14.9	50 (44%)
50-59	236	75.4 ± 22.3	473	85.9 ± 18.4	<0.001	-10.5	128 (54%)
60-69	184	78.0 ± 20.1	639	84.8 ± 18.1	<0.001	-6.8	105 (57%)
70+	75	70.2 ± 22.6	998	84.7 ± 18.1	<0.001	-14.5	32 (43%)
Age group	Number of patients	KOOS Sport*	Number of peers	KOOS Sport*	P-value	MCID 9 **	Number of recovered patients ***
18-29	69	50.6 ± 31.9	152	77.8 ± 27.1	<0.001	-27.2	24 (35%)
30-39	76	41.8 ± 34.8	217	81.2 ± 25.1	<0.001	-39.4	21 (28%)
40-49	111	41.7 ± 31.4	348	77.7 ± 27.3	0.000	-36.0	29 (26%)
50-59	231	42.1 ± 33.8	469	71.1 ± 29.9	0.000	-29.0	70 (30%)
60-69	182	43.0 ± 33.3	631	66.5 ± 31.4	0.000	-23.5	60 (33%)
70+	74	37.6 ± 34.1	982	67.8 ± 31.2	<0.001	-30.2	21 (28%)
Age group	Number of patients	KOOS Quality of life*	Number of peers	KOOS Quality of life*	P-value	MCID 14 **	Number of recovered patients ***
18-29	70	59.4 ± 26.7	152	76.9 ± 25.0	<0.001	-17.5	33 (47%)
30-39	76	51.7 ± 24.7	217	80.8 ± 23.2	0.000	-29.1	25 (33%)
40-49	112	50.7 ± 26.0	351	78.5 ± 23.0	0.000	-27.8	31 (28%)
50-59	236	53.2 ± 29.4	473	73.8 ± 25.9	0.000	-20.6	99 (42%)
60-69	184	57.7 ± 28.8	640	71.2 ± 26.4	<0.001	-13.5	85 (46%)
70+	75	49.3 ± 29.2	996	74.6 ± 25.6	<0.001	-25.3	27 (36%)

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

DISCUSSION

To adequately counsel patients regarding outcome, it is important to understand to what extent they are expected to recover during follow-up. However, it is still unclear how patient-reported outcomes after tibial plateau fractures compare with functional outcome scores of age-related peers from the general population. This multicenter study, which reports patient-reported outcomes from 1101 individuals after tibial plateau fractures, provides a guideline for managing patient expectations by comparing recovery outcomes of operatively and nonoperatively treated patients with age-matched peers from the general population. On average, patients with tibial plateau fractures reported approximately 5% lower patient-reported outcomes for general functioning, pain management and activities of daily living after nonoperative treatment and 10% lower after operative treatment compared to their peers. The most affected domains were sports performance and recreation as well as quality of life, with a decline of 22% after nonoperative treatment and 36% after operative treatment relative to the general population. This effect is particularly pronounced in younger age groups, as they typically start from higher athletic performance levels and experience a substantial reduction in sports capacity.

Level of recovery as compared to age-related peers

Our study reveals that patients recovering from tibial plateau fractures tend to score slightly lower in general physical functioning, pain management, and activities of daily living compared to age-related peers. The most pronounced impairments in all age groups were in sports and recreation as well as quality of life. Importantly, we present age-stratified insights into functional outcomes, enhancing the clinical relevance of our findings. To our knowledge, no other studies have compared a large multicenter cohort of patients with tibial plateau fractures to age-related peers from the general population. This makes it challenging to directly compare our findings with those of other studies. While some studies report on functional outcomes following tibial plateau fractures, their findings are hard to interpret due to the lack of comparisons with pre-injury functional levels or a surrogate such as age-related peers from the general population [8, 10]. Due to differences in activity level, ambulatory status, preexisting comorbidities and coping mechanisms in different age groups, it is likely that age is associated with outcome. Literature regarding reference values of the general population supports that age influences the outcome and showed different functional outcome scores between age groups, especially for the domains sports and recreation as well as quality of life [14, 15]. Van den Berg et al., reported on functional outcome scores of 118 operatively and 42 nonoperatively treated patients and compared these with reference data [10]. Their study showed especially for sport lower outcome scores compared to the general population in both treatment groups, but the impact was more pronounced in operatively treated patients. Our study builds on these preliminary findings and presents outcomes from 1101

patients, both conservatively and operatively treated, stratified by age. Our study showed that the actual impact of these fractures is high for all KOOS-subscales in operatively treated patients, especially for sports and recreation as well as quality of life. In addition, our study showed that the impact is high for sport and recreation as well as quality of life in conservatively treated patients. In 2017, Robertson et al. performed a systematic review on return to sport following tibial plateau fractures [21]. They report on whether patients return to sports or not in a wide range of small studies conducted between 1988 and 2016. They found that 70% of patients with tibial plateau fractures returned to some form of sports, but they didn't report on actual patient-reported outcome scores regarding sports. Our study contributes to this review by including a multicenter cohort larger than the combined total of the 27 studies presented over a period of 28 year in that review. Moreover, we report PROMs and compared them with age-related peers from the general population, providing age- and treatment-stratified analyses of patient- perceived recovery of level of sports. Furthermore, we provided a sub-analysis where we also stratified for the Schatzker classification to show differences in outcome between simple and more complex fractures [16]. Overall, most patients recovering from tibial plateau fractures regain sufficient function to perform well in daily activities. However, many do not return to a level of sports and recreation as well as quality of life comparable to their peers. Nonoperative treated patients, often with minimally displaced fractures, tend to have better recovery outcomes compared to those undergoing operative treatment for more complex fractures. Our study further explores and presents the extent of these recovery outcomes, providing a comprehensive comparison with peers from the general population. Moreover, as the Schatzker classification increases, often indicating more extensive injury, expected recovery outcomes tend to diminish (supplementary data). This study serves as a guideline for managing recovery expectations after tibial plateau fractures across different age groups and fracture types and may facilitate shared decision-making by informing patients and clinicians about expected outcomes.

Limitations

This study has some strengths and limitations which need to be addressed. First, we acknowledge this study has some selection bias which is inherent to the cross-sectional study design due to nonresponse [22]. We tried to reduce the risk of nonresponse bias by approaching all patients multiple times. The response rate was 55% which is in line with literature regarding postal survey studies [23]. Furthermore, the nonresponse analysis showed only small differences in age, sex and treatment between responders and non-responders and no differences in Schatzker classification, suggesting little impact on the generatability of our findings. Secondly, mean follow-up was 6 ± 4 years and therefore our findings are applicable for mid-term follow-up, whereas impact of these fractures at long-term follow-up (i.e. >20 years) remains unknown. Third, we did not account for

fracture severity, sex, or other patient characteristics in our primary analysis, as stratifying by age, sex, treatment, and Schatzker classification would have resulted in groups too small for meaningful comparison— even with a cohort of 1101 patients. To address this, we conducted a sub-analysis stratified by age and Schatzker classification to explore differences in functional outcomes between patients with simple and more complex fracture patterns relative to age-related peers. Lastly, due to the retrospective nature of this study, pre-injury scores were not available. Therefore, we compared the patient-reported functional outcomes with the outcome scores from the general Danish population [15]. Although the Danish population is culturally and demographically quite similar to the Dutch population described in our study, small differences may still be expected. Moreover, for patients who underwent conversion to TKA, we used reference values from patients just before conversion to TKA, to better reflect their functional status at that time. Both these reference values may not fully capture patient-specific recovery but rather reflect recovery at a population level. Therefore, patient-specific recovery should be further investigated in a prospective follow-up study.

Conclusion

In conclusion, this large multicenter study showed that patients with tibial plateau fractures consistently have lower functional outcome scores compared to age-related peers from the general population, with the differences being most pronounced in younger age groups. Patients treated nonoperatively, often with minimally displaced fractures, generally experience better recovery outcomes than those who undergo surgery for more complex fractures. While most patients regain sufficient function to perform daily activities, tibial plateau fractures significantly impact patient's ability to perform sports and recreation and diminish quality of life in all age groups. Most patients will not return to their previous level in these domains compared to age-related peers. These findings can help as a guideline to manage patients' expectations regarding the expected functional outcome during counselling after tibial plateau fractures. Future large prospective multicenter studies are needed, including the patient pre-injury scores, to comprehend more insight into the course of recovery.

REFERENCES

1. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. *Injury*. 2006;37:691–697.
2. Molenaars RJ, Mellema JJ, Doornberg JN, Kloen P. Tibial plateau fracture characteristics: computed tomography mapping of lateral, medial, and bicondylar fractures. *J Bone Joint Surg Am*. 2015;97:1512–1520.
3. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. *EFORT Open Rev*. 2017;1:225–232.
4. Papagelopoulos PJ, Partsinevelos AA, Themistocleous GS, Mavrogenis AF, Korres DS, Soucacos PN. Complications after tibia plateau fracture surgery. *Injury*. 2006;37:475–484.
5. Manidakis N, Dosani A, Dimitriou R, Stengel D, Matthews S, Giannoudis P. Tibial plateau fractures: functional outcome and incidence of osteoarthritis in 125 cases. *Int Orthop*. 2010;34:565–570.
6. Wasserstein D, Henry P, Paterson JM, Kreder HJ, Jenkinson R. Risk of total knee arthroplasty after operatively treated tibial plateau fracture. *J Bone Joint Surg Am*. 2014;96:144–150.
7. Scott CEH, Davidson E, Macdonald DJ, White TO, Keating JF. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. *Bone Joint J*. 2015;97:532–538.
8. Timmers TK, van der Ven DJC, de Vries LS, van Olden GDJ. Functional outcome after tibial plateau fracture osteosynthesis: A mean follow-up of 6years. *Knee*. 2014;21:1210–1215.
9. van Dreumel RLM, Van Wunnik BPW, Janssen L, Simons PCG, Janzing HMJ. Mid- to long-term functional outcome after open reduction and internal fixation of tibial plateau fractures. *Injury*. 2015;46:1608–1612.
10. van den Berg J, Reul M, Nunes Cardozo M, Starovoyt A, Geuens E, Nijs S, et al. Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures. *Int Orthop*. 2017;41:1865–1873.
11. Hap DXF, Kwek EBK. Functional outcomes after surgical treatment of tibial plateau fractures. *J Clin Orthop Trauma*. 2020;11:S11–S15.
12. Vaartjes TP, Assink N, Nijveldt RJ, Van Helden SH, Bosma E, El Moumni M, et al. Functional outcome after nonoperative management of tibial plateau fractures in skeletally mature patients: what sizes of gaps and stepoffs can be accepted? *Clin Orthop Relat Res*. 2022;480:2288–2295.
13. Assink N, Vaartjes TP, Kramer CJS, Bosma E, Nijveldt RJ, ten Brinke JG, et al. What is the patient-reported outcome and complication incidence after operative versus nonoperative treatment of minimally displaced tibial plateau fractures? *Clin Orthop Relat Res*. 2024;482:1744–1752.
14. Paradowski PT, Bergman S, Sundén-Lundius A, Lohmander LS, Roos EM. Knee complaints vary with age and gender in the adult population. Population-based reference data for the knee injury and osteoarthritis outcome score (KOOS). *BMC Musculoskelet Disord*. 2006;7:1–8.
15. Larsen P, Rathleff MS, Roos EM, Elsoe R. Knee injury and osteoarthritis outcome score (KOOS)–National record-based reference values. *Knee*. 2023;43:144–152.
16. Schatzker J, McBroom R. The tibial plateau fracture. The Toronto experience 1968–1975. *Clin Orthop Relat Res*. 1979;138:94–104.
17. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Van den broucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Int J Surg*. 2014;12:1495–1499.

18. De Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of the knee injury and osteoarthritis outcome score: A validation study. *Health Qual Life Outcomes*. 2008;6:1–11.
19. Heir S, Nerhus TK, Røtterud JH, Løken S, Ekeland A, Engebretsen L, et al. Focal cartilage defects in the knee impair quality of life as much as severe osteoarthritis: a comparison of knee injury and osteoarthritis outcome score in 4 patient categories scheduled for knee surgery. *Am J Sports Med*. 2010;38:231–237.
20. Migliorini F, Maffulli N, Schäfer L, Simeone F, Bell A, Hofmann UK. Minimal clinically important difference (MCID), substantial clinical benefit (SCB), and patient-acceptable symptom state (PASS) in patients who have undergone total knee arthroplasty: a systematic review. *Knee Surg Relat Res*. 2024;36:3.
21. Robertson GAJ, Wong SJ, Wood AM. Return to sport following tibial plateau fractures: A systematic review. *World J Orthop*. Baishideng Publishing Group Co; 2017. pp. 574–587.
22. Ramirez-Santana M. Limitations and biases in cohort studies. *cohort studies.in health sciences*. InTech; 2018.
23. Meyer VM, Benjamins S, El Moumni M, Lange JFM, Pol RA. Global overview of response rates in patient and health care professional surveys in surgery a systematic review. *Ann Surg*. 2022;275:E75–E81.

APPENDIX

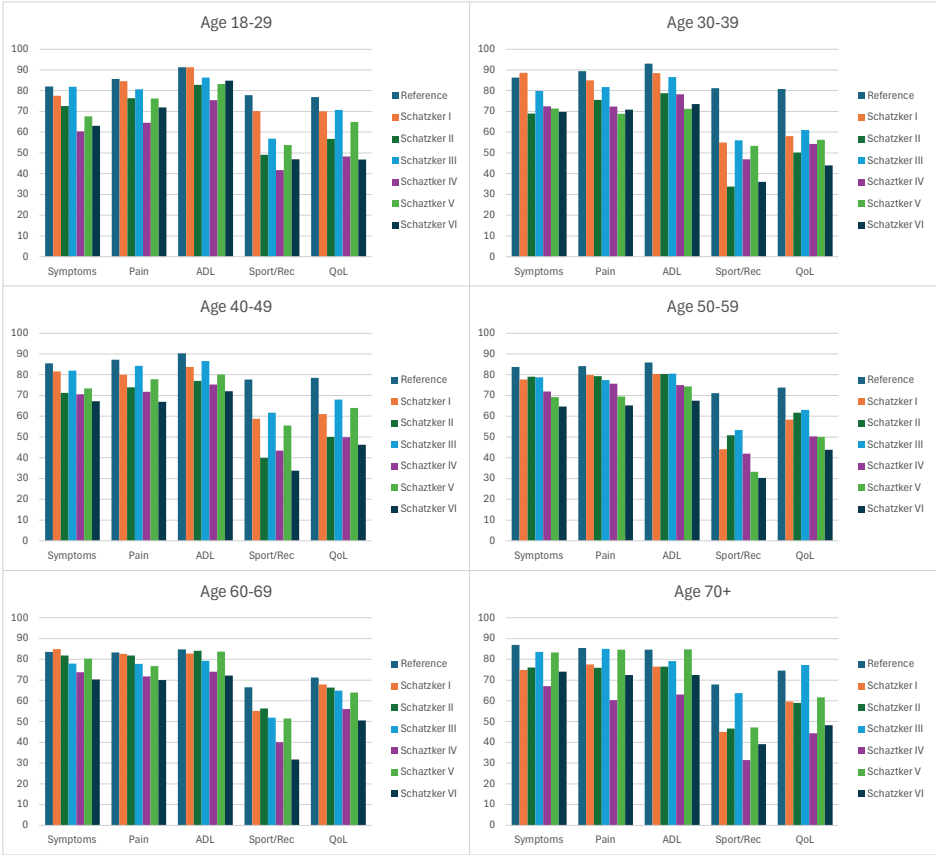


Figure 1 The average KOOS-score for each subscale of the different age groups stratified by Schatzker classification compared with age-related peers.

Table 1 The average KOOS-score of each age group stratified by Schatzker classification compared with age-related peers

Age 18-29		Outcome score after Tibial plateau fracture				Outcome score general population				Difference on a scale of 0-100	
Classification	Number of patients	KOOS Symptoms		Number of peers	KOOS Symptoms	P-value*	MCID 9 **	Number of recovered patients ***			
Schatzker I	14	77.6 ± 20.9		153	82.0 ± 18.1	0.391	-4.4	10 (71)			
Schatzker II	36	72.6 ± 18.5		153	82.0 ± 18.1	0.006	-9.4	18 (50)			
Schatzker III	24	81.9 ± 15.7		153	82.0 ± 18.1	0.980	-0.1	18 (75)			
Schatzker IV	12	60.4 ± 20.7		153	82.0 ± 18.1	<0.001	-21.6	3 (25)			
Schatzker V	13	67.6 ± 28.1		153	82.0 ± 18.1	0.093	-14.4	7 (54)			
Schatzker VI	6	63.1 ± 20.3		153	82.0 ± 18.1	0.013	-18.9	2 (33)			
Classification	Number of patients	KOOS Pain		Number of peers	KOOS Pain	P-value*	MCID 12 **	Number of recovered patients ***			
Schatzker I	14	84.6 ± 17.3		153	85.6 ± 18.2	0.844	-1.0	11 (79)			
Schatzker II	36	76.4 ± 20.4		153	85.6 ± 18.2	0.008	-9.2	22 (61)			
Schatzker III	24	80.7 ± 15.9		153	85.6 ± 18.2	0.214	-4.9	16 (67)			
Schatzker IV	12	64.6 ± 25.0		153	85.6 ± 18.2	0.015	-21	5 (42)			
Schatzker V	13	76.2 ± 22.8		153	85.6 ± 18.2	0.082	-9.4	8 (62)			
Schatzker VI	6	72.0 ± 14.5		153	85.6 ± 18.2	0.073	-13.6	2 (33)			
Classification	Number of patients	KOOS ADL		Number of peers	KOOS ADL	P-value*	MCID 10 **	Number of recovered patients ***			
Schatzker I	14	91.3 ± 18.5		152	91.3 ± 14.1	1.000	0.0	13 (93)			
Schatzker II	36	82.8 ± 18.3		152	91.3 ± 14.1	0.012	-8.5	22 (61)			
Schatzker III	24	86.3 ± 16.1		152	91.3 ± 14.1	0.115	-5.0	17 (71)			
Schatzker IV	12	75.4 ± 22.4		152	91.3 ± 14.1	<0.001	-15.9	6 (50)			
Schatzker V	13	83.2 ± 21.7		152	91.3 ± 14.1	0.209	-8.1	9 (69)			
Schatzker VI	6	84.9 ± 10.4		152	91.3 ± 14.1	0.274	-6.4	4 (67)			
Classification	Number of patients	KOOS Sport/Rec		Number of peers	KOOS Sport/Rec	P-value*	MCID 9 **	Number of recovered patients ***			
Schatzker I	14	70.2 ± 28.3		152	77.8 ± 27.1	0.319	-7.6	7 (50)			
Schatzker II	36	49.1 ± 32.9		152	77.8 ± 27.1	<0.001	-28.7	12 (33)			

Age 18-29		Outcome score after Tibial plateau fracture		Outcome score general population		Difference on a scale of 0-100	
Schatzker III	24	56.9 ± 31.1	152	77.8 ± 27.1	<0.001	-20.9	11 (46)
Schatzker IV	12	41.7 ± 32.7	152	77.8 ± 27.1	<0.001	-36.1	4 (33)
Schatzker V	13	53.8 ± 36.3	152	77.8 ± 27.1	0.036	-24.0	6 (46)
Schatzker VI	5	47.0 ± 30.3	152	77.8 ± 27.1	0.014	-30.8	1 (20)
Classification	Number of patients	KOOS	Number of peers	KOOS	P-value*	MCID 14 **	Number of recovered patients ***
		Quality of life		Quality of life			
Schatzker I	14	70.1 ± 18.2	152	76.9 ± 25.0	0.322	-6.8	9 (64)
Schatzker II	36	56.8 ± 26.3	152	76.9 ± 25.0	<0.001	-20.1	14 (39)
Schatzker III	24	70.8 ± 21.2	152	76.9 ± 25.0	0.259	-6.1	15 (63)
Schatzker IV	12	48.3 ± 30.9	152	76.9 ± 25.0	<0.001	-28.6	4 (33)
Schatzker V	13	64.9 ± 28.7	152	76.9 ± 25.0	0.103	-12.0	8 (62)
Schatzker VI	6	46.9 ± 27.3	152	76.9 ± 25.0	0.005	-30.0	1 (17)

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Age 30-39		Outcome score after Tibial plateau fracture			Outcome score general population			Difference on a scale of 0-100		
Classification	Number of patients	KOOS Symptoms	Number of peers	KOOS Symptoms	P-value*	MCID 9 **	Number of recovered patients ***			
Schatzker I	10	88.6 ± 13.1	218	86.3 ± 14.7	0.628	+2.3	8 (80)			
Schatzker II	26	69.0 ± 19.9	218	86.3 ± 14.7	<0.001	-17.3	9 (35)			
Schatzker III	28	79.8 ± 21.1	218	86.3 ± 14.7	0.124	-6.5	18 (64)			
Schatzker IV	24	72.5 ± 20.2	218	86.3 ± 14.7	0.003	-13.8	10 (42)			
Schatzker V	4	71.4 ± 27.8	218	86.3 ± 14.7	0.363	-14.9	2 (50)			
Schatzker VI	10	69.8 ± 25.3	218	86.3 ± 14.7	0.070	-16.5	4 (40)			
Classification	Number of patients	KOOS Pain	Number of peers	KOOS Pain	P-value*	MCID 12 **	Number of recovered patients ***			
Schatzker I	10	85.0 ± 14.4	218	89.4 ± 15.3	0.374	-4.4	8 (80)			
Schatzker II	26	75.5 ± 22.3	218	89.4 ± 15.3	0.004	-13.9	15 (58)			
Schatzker III	28	81.7 ± 19.7	218	89.4 ± 15.3	0.055	-7.7	20 (71)			
Schatzker IV	24	72.3 ± 23.9	218	89.4 ± 15.3	0.002	-17.1	10 (42)			
Schatzker V	4	68.8 ± 25.2	218	89.4 ± 15.3	0.201	-20.6	2 (50)			
Schatzker VI	10	70.9 ± 29.7	218	89.4 ± 15.3	0.081	-18.5	6 (60)			
Classification	Number of patients	KOOS ADL	Number of peers	KOOS ADL	P-value*	MCID 10 **	Number of recovered patients ***			
Schatzker I	10	88.5 ± 15.4	217	93.0 ± 12.5	0.272	-4.5	8 (80)			
Schatzker II	26	78.8 ± 21.1	217	93.0 ± 12.5	0.002	-14.2	14 (54)			
Schatzker III	28	86.6 ± 18.0	217	93.0 ± 12.5	0.078	-6.4	22 (79)			
Schatzker IV	24	78.3 ± 23.1	217	93.0 ± 12.5	0.005	-14.7	13 (54)			
Schatzker V	4	71.3 ± 32.7	217	93.0 ± 12.5	0.276	-21.7	2 (50)			
Schatzker VI	10	73.6 ± 27.8	217	93.0 ± 12.5	0.055	-19.4	4 (40)			
Classification	Number of patients	KOOS Sport/Rec	Number of peers	KOOS Sport/Rec	P-value*	MCID 9 **	Number of recovered patients ***			
Schatzker I	10	55.0 ± 38.2	217	81.2 ± 25.1	0.059	-26.2	5 (50)			
Schatzker II	26	33.8 ± 34.0	217	81.2 ± 25.1	<0.001	-47.4	5 (19)			
Schatzker III	27	56.1 ± 35.4	217	81.2 ± 25.1	0.001	-25.1	11 (41)			

Age 30-39	Outcome score after Tibial plateau fracture		Outcome score general population		Difference on a scale of 0-100	
Schatzker IV	24	47.0 ± 36.9	217	81.2 ± 25.1	<0.001	-34.2
Schatzker V	4	53.4 ± 41.7	217	81.2 ± 25.1	0.275	-27.8
Schatzker VI	10	36.1 ± 36.7	217	81.2 ± 25.1	0.004	-45.1
Classification	Number of patients	KOOS	Number of peers	KOOS	P-value*	MCID 14 **
		Quality of life		Quality of life		Number of recovered patients ***
Schatzker I	10	58.1 ± 26.7	217	80.8 ± 23.2	0.003	-22.7
Schatzker II	26	50.2 ± 20.5	217	80.8 ± 23.2	<0.001	-30.6
Schatzker III	27	61.0 ± 25.2	217	80.8 ± 23.2	<0.001	-19.8
Schatzker IV	24	54.4 ± 27.5	217	80.8 ± 23.2	<0.001	-26.3
Schatzker V	4	56.3 ± 22.2	217	80.8 ± 23.2	0.037	-24.5
Schatzker VI	10	44.0 ± 28.7	217	80.8 ± 23.2	<0.001	-36.8

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Age 40-49		Outcome score after Tibial plateau fracture				Outcome score general population				Difference on a scale of 0-100					
Classification	Number of patients	COOS Symptoms	Number of peers	COOS Symptoms	P-value*	MCID 9 **	Number of recovered patients***	Classification	Number of patients	COOS Pain	Number of peers	COOS Pain	P-value*	MCID 12 **	Number of recovered patients***
Schatzker I	13	81.6 ± 15.3	351	85.5 ± 16.3	0.397	-3.9	8 (62)	Schatzker I	13	80.0 ± 19.9	351	87.2 ± 17.1	0.139	-7.2	7 (54)
Schatzker II	58	71.3 ± 20.6	351	85.5 ± 16.3	<0.001	-14.2	28 (48)	Schatzker II	58	74.0 ± 21.7	351	87.2 ± 17.1	<0.001	-13.2	30 (52)
Schatzker III	26	82.0 ± 17.3	351	85.5 ± 16.3	0.293	-3.5	18 (69)	Schatzker III	26	84.3 ± 19.2	351	87.2 ± 17.1	0.409	-2.9	19 (73)
Schatzker IV	29	70.6 ± 19.5	351	85.5 ± 16.3	<0.001	-14.9	11 (38)	Schatzker IV	29	71.8 ± 19.8	351	87.2 ± 17.1	<0.001	-15.4	12 (41)
Schatzker V	10	73.4 ± 21.9	351	85.5 ± 16.3	0.023	-12.1	5 (50)	Schatzker V	10	77.8 ± 22.5	351	87.2 ± 17.1	0.090	-9.4	6 (60)
Schatzker VI	22	67.2 ± 26.7	351	85.5 ± 16.3	0.004	-18.3	10 (45)	Schatzker VI	22	67.0 ± 26.5	351	87.2 ± 17.1	0.002	-20.2	9 (41)
Classification	Number of patients	COOS Pain	Number of peers	COOS Pain	P-value* <td>MCID 12 **<td>Number of recovered patients***</td><td>Classification</td><td>Number of patients</td><td>COOS ADL</td><td>Number of peers</td><td>COOS ADL</td><td>P-value*<td>MCID 10 **<td>Number of recovered patients***</td></td></td></td>	MCID 12 ** <td>Number of recovered patients***</td> <td>Classification</td> <td>Number of patients</td> <td>COOS ADL</td> <td>Number of peers</td> <td>COOS ADL</td> <td>P-value*<td>MCID 10 **<td>Number of recovered patients***</td></td></td>	Number of recovered patients***	Classification	Number of patients	COOS ADL	Number of peers	COOS ADL	P-value* <td>MCID 10 **<td>Number of recovered patients***</td></td>	MCID 10 ** <td>Number of recovered patients***</td>	Number of recovered patients***
Schatzker I	13	83.8 ± 19.0	350	90.4 ± 15.3	0.131	-6.6	9 (69)	Schatzker I	13	83.8 ± 19.0	350	90.4 ± 15.3	0.131	-6.6	9 (69)
Schatzker II	58	77.1 ± 20.1	350	90.4 ± 15.3	<0.001	-13.3	29 (50)	Schatzker II	58	77.1 ± 20.1	350	90.4 ± 15.3	<0.001	-13.3	29 (50)
Schatzker III	26	86.6 ± 16.0	350	90.4 ± 15.3	0.224	-3.8	17 (65)	Schatzker III	26	86.6 ± 16.0	350	90.4 ± 15.3	0.224	-3.8	17 (65)
Schatzker IV	29	75.3 ± 19.2	350	90.4 ± 15.3	<0.001	-15.1	11 (38)	Schatzker IV	29	75.3 ± 19.2	350	90.4 ± 15.3	<0.001	-15.1	11 (38)
Schatzker V	10	80.2 ± 21.2	350	90.4 ± 15.3	0.164	-10.2	6 (60)	Schatzker V	10	80.2 ± 21.2	350	90.4 ± 15.3	0.164	-10.2	6 (60)
Schatzker VI	22	72.1 ± 22.5	350	90.4 ± 15.3	0.001	-18.3	8 (36)	Schatzker VI	22	72.1 ± 22.5	350	90.4 ± 15.3	0.001	-18.3	8 (36)
Classification	Number of patients	COOS Sport/Rec	Number of peers	COOS Sport/Rec	P-value* <td>MCID 9 **<td>Number of recovered patients***</td><td>Classification</td><td>Number of patients</td><td>COOS Sport/Rec</td><td>Number of peers</td><td>COOS Sport/Rec</td><td>P-value*<td>MCID 9 **<td>Number of recovered patients***</td></td></td></td>	MCID 9 ** <td>Number of recovered patients***</td> <td>Classification</td> <td>Number of patients</td> <td>COOS Sport/Rec</td> <td>Number of peers</td> <td>COOS Sport/Rec</td> <td>P-value*<td>MCID 9 **<td>Number of recovered patients***</td></td></td>	Number of recovered patients***	Classification	Number of patients	COOS Sport/Rec	Number of peers	COOS Sport/Rec	P-value* <td>MCID 9 **<td>Number of recovered patients***</td></td>	MCID 9 ** <td>Number of recovered patients***</td>	Number of recovered patients***
Schatzker I	13	58.8 ± 31.7	348	77.7 ± 27.3	0.015	-18.9	5 (38)	Schatzker I	13	58.8 ± 31.7	348	77.7 ± 27.3	0.015	-18.9	5 (38)
Schatzker II	56	40.0 ± 28.8	348	77.7 ± 27.3	0.000	-37.7	11 (20)	Schatzker II	56	40.0 ± 28.8	348	77.7 ± 27.3	0.000	-37.7	11 (20)
Schatzker III	26	61.8 ± 35.6	348	77.7 ± 27.3	0.034	-15.9	14 (54)	Schatzker III	26	61.8 ± 35.6	348	77.7 ± 27.3	0.034	-15.9	14 (54)

Age 40-49		Outcome score after Tibial plateau fracture		Outcome score general population		Difference on a scale of 0-100	
Schatzker IV	29	43.5 ± 29.9	348	77.7 ± 27.3	<0.001	-34.2	9 (31)
Schatzker V	10	55.6 ± 42.6	348	77.7 ± 27.3	0.137	-22.1	5 (50)
Schatzker VI	22	33.8 ± 31.9	348	77.7 ± 27.3	<0.001	-43.9	4 (18)
Classification	Number of patients	KOOS Quality of life	Number of peers	KOOS Quality of life	P-value*	MCID 14 **	Number of recovered patients ***
Schatzker I	13	61.1 ± 26.5	351	78.5 ± 23.0	0.008	-17.4	5 (38)
Schatzker II	57	50.1 ± 25.4	351	78.5 ± 23.0	<0.001	-28.4	15 (26)
Schatzker III	26	68.1 ± 25.0	351	78.5 ± 23.0	0.028	-10.4	15 (58)
Schatzker IV	29	49.9 ± 26.3	351	78.5 ± 23.0	<0.001	-28.6	8 (28)
Schatzker V	10	64.0 ± 31.6	351	78.5 ± 23.0	0.183	-14.5	5 (50)
Schatzker VI	22	46.3 ± 26.3	351	78.5 ± 23.0	<0.001	-32.2	5 (23)

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Age 50-59		Outcome score after Tibial plateau fracture				Outcome score general population				Difference on a scale of 0-100	
Classification	Number of patients	KOOS Symptoms	Number of peers	KOOS Symptoms	P-value*	MCID 9 **	Number of recovered patients ***				
Schatzker I	21	77.7 ± 17.6	473	83.7 ± 17.3	0.121	-6.0	14 (67)				
Schatzker II	114	79.1 ± 20.0	473	83.7 ± 17.3	0.025	-4.6	73 (64)				
Schatzker III	72	78.8 ± 20.8	473	83.7 ± 17.3	0.061	-4.9	47 (65)				
Schatzker IV	37	71.9 ± 22.2	473	83.7 ± 17.3	0.003	-11.8	18 (49)				
Schatzker V	28	69.3 ± 22.1	473	83.7 ± 17.3	0.002	-14.4	11 (39)				
Schatzker VI	57	64.7 ± 21.5	473	83.7 ± 17.3	<0.001	-19.0	18 (32)				
Classification	Number of patients	KOOS Pain	Number of peers	KOOS Pain	P-value* <td>MCID 12 **<td>Number of recovered patients ***</td></td>	MCID 12 ** <td>Number of recovered patients ***</td>	Number of recovered patients ***				
Schatzker I	21	79.8 ± 18.7	473	84.2 ± 19.0	0.299	-4.4	15 (71)				
Schatzker II	114	79.3 ± 21.6	473	84.2 ± 19.0	0.028	-4.9	76 (67)				
Schatzker III	72	77.5 ± 24.4	473	84.2 ± 19.0	0.028	-6.7	44 (61)				
Schatzker IV	37	75.7 ± 24.4	473	84.2 ± 19.0	0.045	-8.5	24 (65)				
Schatzker V	28	69.5 ± 25.1	473	84.2 ± 19.0	0.005	-14.7	15 (54)				
Schatzker VI	57	65.2 ± 24.5	473	84.2 ± 19.0	<0.001	-19.0	23 (40)				
Classification	Number of patients	KOOS ADL	Number of peers	KOOS ADL	P-value* <td>MCID 10 **<td>Number of recovered patients ***</td></td>	MCID 10 ** <td>Number of recovered patients ***</td>	Number of recovered patients ***				
Schatzker I	21	80.4 ± 16.6	473	85.9 ± 18.4	0.179	-5.5	15 (71)				
Schatzker II	114	80.4 ± 21.0	473	85.9 ± 18.4	0.011	-5.5	70 (61)				
Schatzker III	72	80.5 ± 22.4	473	85.9 ± 18.4	0.055	-5.4	47 (65)				
Schatzker IV	37	75.0 ± 24.6	473	85.9 ± 18.4	0.012	-10.9	24 (65)				
Schatzker V	28	74.4 ± 20.5	473	85.9 ± 18.4	0.001	-11.5	15 (54)				
Schatzker VI	57	67.5 ± 22.2	473	85.9 ± 18.4	<0.001	-18.4	21 (37)				
Classification	Number of patients	KOOS Sport/Rec	Number of peers	KOOS Sport/Rec	P-value* <td>MCID 9 **<td>Number of recovered patients ***</td></td>	MCID 9 ** <td>Number of recovered patients ***</td>	Number of recovered patients ***				
Schatzker I	21	44.2 ± 32.9	469	71.1 ± 29.9	<0.001	-26.9	6 (29)				
Schatzker II	111	50.8 ± 35.0	469	71.1 ± 29.9	<0.001	-20.3	45 (41)				
Schatzker III	72	53.4 ± 35.4	469	71.1 ± 29.9	<0.001	-17.7	32 (44)				

Age 50-59	Outcome score after Tibial plateau fracture		Outcome score general population		Difference on a scale of 0-100	
Schatzker IV	36	42.0 ± 34.5	469	71.1 ± 29.9	<0.001	-29.1
Schatzker V	27	33.3 ± 33.8	469	71.1 ± 29.9	<0.001	-37.8
Schatzker VI	55	30.3 ± 28.3	469	71.1 ± 29.9	0.000	-40.8
Classification	Number of patients	KOOS	Number of peers	KOOS	P-value*	MCID 14 **
		Quality of life		Quality of life		Number of recovered patients ***
Schatzker I	21	58.4 ± 23.9	473	73.8 ± 25.9	0.008	-15.4
Schatzker II	114	61.8 ± 29.5	473	73.8 ± 25.9	<0.001	-12.0
Schatzker III	72	63.1 ± 29.6	473	73.8 ± 25.9	0.001	-10.7
Schatzker IV	37	50.3 ± 27.9	473	73.8 ± 25.9	<0.001	-23.5
Schatzker V	28	50.1 ± 30.4	473	73.8 ± 25.9	<0.001	-23.7
Schatzker VI	57	43.9 ± 26.8	473	73.8 ± 25.9	<0.001	-29.9

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Age 60-69	Outcome score after Tibial plateau fracture			Outcome score general population			Difference on a scale of 0-100		
	Number of patients	KOOS Symptoms	Number of peers	KOOS Symptoms	P-value*	MCID 9 **	Number of recovered patients ***		
Schatzker I	11	84.9 ± 18.7	640	83.6 ± 17.3	0.805	+1.3	8 (73)		
Schatzker II	105	81.9 ± 19.6	640	83.6 ± 17.3	0.404	-1.7	76 (72)		
Schatzker III	65	77.9 ± 19.3	640	83.6 ± 17.3	0.013	-5.7	41 (63)		
Schatzker IV	36	73.8 ± 20.4	640	83.6 ± 17.3	0.001	-9.8	17 (47)		
Schatzker V	12	80.4 ± 20.5	640	83.6 ± 17.3	0.527	-3.2	7 (58)		
Schatzker VI	48	70.3 ± 19.5	640	83.6 ± 17.3	<0.001	-13.3	22 (46)		
Classification	Number of patients	KOOS Pain	Number of peers	KOOS Pain	P-value*	MCID 12 **	Number of recovered patients ***		
Schatzker I	11	82.6 ± 21.4	640	83.3 ± 19.3	0.905	-0.7	8 (73)		
Schatzker II	105	81.8 ± 20.1	640	83.3 ± 19.3	0.463	-1.5	73 (70)		
Schatzker III	65	77.8 ± 22.0	640	83.3 ± 19.3	0.031	-5.5	42 (65)		
Schatzker IV	35	71.7 ± 24.1	640	83.3 ± 19.3	0.008	-11.6	19 (54)		
Schatzker V	12	76.7 ± 23.6	640	83.3 ± 19.3	0.243	-6.6	8 (67)		
Schatzker VI	48	70.0 ± 23.7	640	83.3 ± 19.3	<0.001	-13.3	23 (48)		
Classification	Number of patients	KOOS ADL	Number of peers	KOOS ADL	P-value*	MCID 10 **	Number of recovered patients ***		
Schatzker I	11	82.8 ± 21.8	639	84.8 ± 18.1	0.717	-2.0	7 (64)		
Schatzker II	105	84.1 ± 18.0	639	84.8 ± 18.1	0.713	-0.7	72 (69)		
Schatzker III	65	79.3 ± 20.4	639	84.8 ± 18.1	0.021	-5.5	39 (60)		
Schatzker IV	36	74.0 ± 21.6	639	84.8 ± 18.1	<0.001	-10.8	18 (50)		
Schatzker V	12	83.7 ± 18.4	639	84.8 ± 18.1	0.835	-1.1	9 (75)		
Schatzker VI	48	72.2 ± 21.1	639	84.8 ± 18.1	<0.001	-12.6	23 (48)		

Age 60-69	Outcome score after Tibial plateau fracture				Outcome score general population			Difference on a scale of 0-100	
Classification	Number of patients	KOOS Sport/Rec	Number of peers	KOOS Sport/Rec	P-value*	MCID 9 **	Number of recovered patients ***		
Schatzker I	9	55.1 ± 34.6	631	66.5 ± 31.4	0.281	-11.4	4 (44)		
Schatzker II	102	56.3 ± 33.4	631	66.5 ± 31.4	0.003	-10.2	53 (52)		
Schatzker III	63	51.8 ± 34.7	631	66.5 ± 31.4	<0.001	-14.7	29 (46)		
Schatzker IV	36	40.1 ± 33.5	631	66.5 ± 31.4	<0.001	-26.4	9 (25)		
Schatzker V	12	51.4 ± 34.2	631	66.5 ± 31.4	0.100	-15.1	5 (42)		
Schatzker VI	48	31.7 ± 29.1	631	66.5 ± 31.4	<0.001	-34.8	10 (21)		
Classification	Number of patients	KOOS Quality of life	Number of peers	KOOS Quality of life	P-value*	MCID 14 **	Number of recovered patients ***		
Schatzker I	11	67.8 ± 34.2	640	71.2 ± 26.4	0.674	-3.4	7 (64)		
Schatzker II	105	66.4 ± 28.2	640	71.2 ± 26.4	0.088	-4.8	62 (59)		
Schatzker III	65	64.9 ± 28.1	640	71.2 ± 26.4	0.069	-6.3	38 (58)		
Schatzker IV	36	56.1 ± 29.2	640	71.2 ± 26.4	<0.001	-15.1	14 (39)		
Schatzker V	12	64.0 ± 29.2	640	71.2 ± 26.4	0.351	-7.2	7 (58)		
Schatzker VI	48	50.5 ± 27.6	640	71.2 ± 26.4	<0.001	-20.7	18 (38)		

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Age 70+	Outcome score after Tibial plateau fracture				Outcome score general population			Difference on a scale of 0-100	
Classification	Number of patients	KOOS Symptoms	Number of peers	KOOS Symptoms	P-value*	MCID 9 **	Number of recovered patients ***		
Schatzker I	8	74.8 ± 25.4	1007	87.0 ± 16.2	0.217	-12.2	5 (63)		
Schatzker II	45	76.0 ± 24.0	1007	87.0 ± 16.2	0.004	-11.0	26 (58)		
Schatzker III	33	83.6 ± 21.9	1007	87.0 ± 16.2	0.383	-3.4	24 (73)		
Schatzker IV	20	67.0 ± 20.3	1007	87.0 ± 16.2	<0.001	-20.0	7 (35)		
Schatzker V	5	83.3 ± 20.3	1007	87.0 ± 16.2	0.611	-3.7	3 (60)		
Schatzker VI	16	74.1 ± 19.8	1007	87.0 ± 16.2	0.002	-12.9	8 (50)		
Classification	Number of patients	KOOS Pain	Number of peers	KOOS Pain	P-value* <td>MCID 12 **</td> <td>Number of recovered patients ***</td>	MCID 12 **	Number of recovered patients ***		
Schatzker I	8	77.5 ± 22.9	1004	85.4 ± 18.0	0.218	-7.9	4 (50)		
Schatzker II	45	75.9 ± 25.6	1004	85.4 ± 18.0	0.018	-9.5	28 (62)		
Schatzker III	33	85.1 ± 20.4	1004	85.4 ± 18.0	0.925	-0.3	26 (79)		
Schatzker IV	20	60.3 ± 24.6	1004	85.4 ± 18.0	<0.001	-25.1	5 (25)		
Schatzker V	5	84.6 ± 22.8	1004	85.4 ± 18.0	0.921	-0.8	4 (80)		
Schatzker VI	16	72.4 ± 24.9	1004	85.4 ± 18.0	0.055	-13.0	9 (56)		
Classification	Number of patients	KOOS ADL	Number of peers	KOOS ADL	P-value* <td>MCID 10 **</td> <td>Number of recovered patients ***</td>	MCID 10 **	Number of recovered patients ***		
Schatzker I	8	76.5 ± 21.7	998	84.7 ± 18.1	0.203	-8.2	4 (50)		
Schatzker II	45	76.4 ± 24.3	998	84.7 ± 18.1	0.028	-8.3	27 (60)		
Schatzker III	33	79.1 ± 28.8	998	84.7 ± 18.1	0.275	-5.6	24 (73)		
Schatzker IV	20	63.0 ± 22.0	998	84.7 ± 18.1	<0.001	-21.7	5 (25)		
Schatzker V	5	84.8 ± 18.6	998	84.7 ± 18.1	0.990	+0.1	4 (80)		
Schatzker VI	16	72.4 ± 21.7	998	84.7 ± 18.1	0.007	-12.3	7 (44)		
Classification	Number of patients	KOOS Sport/Rec	Number of peers	KOOS Sport/Rec	P-value* <td>MCID 9 **</td> <td>Number of recovered patients ***</td>	MCID 9 **	Number of recovered patients ***		
Schatzker I	8	45.0 ± 40.0	982	67.8 ± 31.2	0.040	-22.8	3 (38)		
Schatzker II	42	46.6 ± 37.0	982	67.8 ± 31.2	<0.001	-21.2	18 (43)		
Schatzker III	26	63.7 ± 36.6	982	67.8 ± 31.2	0.510	-4.1	16 (62)		

Age 70+	Outcome score after Tibial plateau fracture		Outcome score general population			Difference on a scale of 0-100	
Schatzker IV	20	31.5 ± 32.5	982	67.8 ± 31.2	<0.001	-36.3	4 (20)
Schatzker V	5	47.2 ± 34.7	982	67.8 ± 31.2	0.141	-20.6	2 (40)
Schatzker VI	16	39.1 ± 36.3	982	67.8 ± 31.2	<0.001	-28.7	5 (31)
Classification	Number of patients	KOOS	Number of peers	KOOS	P-value*	MCID 14 **	Number of recovered patients ***
		Quality of life		Quality of life			
Schatzker I	8	59.6 ± 31.4	996	74.6 ± 25.6	0.100	-15.0	4 (50)
Schatzker II	45	59.0 ± 33.7	996	74.6 ± 25.6	0.004	-15.6	23 (51)
Schatzker III	32	77.3 ± 25.4	996	74.6 ± 25.6	0.557	-2.7	24 (75)
Schatzker IV	20	44.4 ± 28.7	996	74.6 ± 25.6	<0.001	-30.2	5 (25)
Schatzker V	5	61.7 ± 27.1	996	74.6 ± 25.6	0.261	-12.9	3 (60)
Schatzker VI	16	48.2 ± 30.1	996	74.6 ± 25.6	<0.001	-26.4	6 (38)

* The values are given as mean and standard deviation.

** The cursive numbers indicate KOOS-scores exceeding the minimal clinically important difference (MCID).

*** The number and percentage of patients that recovered within the MCID range of the outcome scores from age-related peers.

Chapter 8



UNDER EMBARGO

What is the course of recovery regarding symptoms, pain, daily activities, sports and quality of life after tibial plateau fractures within the first year after injury: a prospective multicenter study including 280 patients

This chapter presents the initial results of the PROTIB study, conducted as a prospective multicenter collaboration.

University Medical Center Groningen

Thijs P. Vaartjes, Lotte R. van der Linden, Job N. Doornberg, Nick Assink, Frank F.A. IJpma

Martini hospital

Emma Westerduin, Samantha Damude, Eelke Bosma

Isala hospitals

Rens A. van der Linde, Djoke Douma, Robert J. Nijveldt

Frisius MC

Romke Rozema, Arvid Munzebrock

Gelre Hospitals

Joost P.H. van Leur, Leonie R. van der Werf, Joost G. ten Brinke

This chapter is not published

Chapter 9



General discussion

Although tibial plateau fractures only account for 1-2 % of all fractures, they have a major impact on the patient's life and are among the most challenging injuries to treat due to the complex fracture morphology. The overall aim of the research presented in this thesis is to gain more insight in patient-reported functional outcomes after tibial plateau fractures. To explore this topic in depth, the thesis covers all aspects of the injury — from the initial trauma to recovery — and is divided into three parts: (1) How do they occur, (2) How are they treated, and (3) How do they recover. This chapter provides an overview and discussion on the main findings of the research of this thesis and presents future clinical perspectives.

How do they occur

Accidents can happen in a split second during all kinds of daily activities. These accidents range from relatively simple, low-energy falls — such as tripping over a sidewalk — to more severe, high-energy incidents like motorcycle crashes [1]. The damage to the tibial plateau results from the energy generated during the trauma, which can be divided into a varus or valgus force combined with axial load [2,3]. Besides damage of the tibial plateau itself, these fractures are also associated with severe trauma of the surrounding soft tissues (including ligaments and menisci) with reported incidences ranging from 93% to 99% [4–6]. Despite the different impact of high- and low-energy trauma mechanisms, there is limited research comparing outcomes after different injury force mechanisms, which is important to adequately counsel patients regarding their prognosis. In **Chapter 2**, differences in patient characteristics and clinical outcomes after high- and low-energy trauma were compared. Results showed that only 12% of all tibial plateau fractures were caused by high-energy trauma mechanisms, predominantly in younger males. With 88% of the fractures caused by low-energy trauma mechanisms, most of these fractures appear to be the result of low impact traumas. High-energy traumas caused more severe fractures and resulted in slightly worse patient-reported functional outcome scores, but despite the higher number of complications, there was no substantial difference in conversion to total knee arthroplasty (TKA). However, since high-energy traumas mostly occur in the younger patient population, the high rate of conversion to total knee arthroplasty after high-energy trauma highlights the severity of such injuries. This is because surgeons are more conservative in recommending TKA for younger patients, as the primary indication for TKA is elderly with degenerative or post-traumatic osteoarthritis. Interestingly, low-energy trauma also resulted in severe Schatzker VI fractures in elderly patients. This is most likely the result of the higher incidence of osteoporosis in elderly patients, which means that less force is needed to get more severe fractures [7,8]. Therefore, the traditional distinction between high- and low-energy injuries slowly decreases in the aging population, because low-energy trauma in elderly patients no longer indicates that the sustained injuries are less complex. Nevertheless, surgeons should be aware that treatment of patients with tibial

plateau fractures caused by high-energy trauma is challenging, as there is a higher risk of complications and these fractures result in worse outcomes during follow-up. Besides the amount of energy during trauma causing different types of tibial plateau fractures, Xie et al. recently showed that the position of the leg and the direction of the force during the injury influence the creation of one of six characteristic and unique 3D fracture patterns [2]. Each of these unique patterns appeared to be related to specific types of soft tissue injuries. However, it remained unknown whether these different injury patterns were also associated with functional outcomes. This may be important as it could allow surgeons to identify patients who are more likely to have worse outcomes. Therefore, in **Chapter 3**, the association between these unique fracture patterns and functional outcomes was assessed. Our results showed that these different injury mechanisms are not only related to different types of soft tissue injuries but also have a different impact on patient-reported functional outcomes. Particularly fractures which were caused by the impact of varus-flexion forces resulted in lower patient-reported functional outcome scores and were associated with increased risks of conversion to total knee arthroplasty. This type of injury also resulted in more reoperations for soft tissues repair, including (postero)lateral ligaments and menisci. To adequately examine associated soft tissue injuries in tibial plateau fractures, an additional MRI should be required, but due to the costs and scan duration, it is impossible to perform this on all patients. Identification of the unique fracture patterns as described by Xie et al. allows surgeons to not only identify associated soft tissue injuries but also helps them select patients who would potentially benefit from an additional MRI. Our findings suggest that patients with a tibial plateau fracture should undergo MRI more often in order to better assess the extent of soft tissue injury and enable the surgeon to be prepared and address this during surgery. This should especially be considered in fractures caused by varus-flexion injuries, since these fractures are associated with more soft tissue damage and worse clinical outcomes. In conclusion, the first part of this thesis aimed to return to the origin of the injury and explore why the type of injury matters. Although tibial plateau fractures are the result of high- and low-energy trauma, the impact of these traumas not always correlates with the severity of the fracture. Our study added to the current knowledge by showing that it is not only important to incorporate the injury mechanism and fracture severity, but also to visualize the direction of forces during the accident. When surgeons understand how the injury occurred, they can provide more patient specific treatment, as each type of injury has different fracture patterns and associated soft-tissue injuries, resulting in different outcomes.

How are they treated

The principle “Primum non nocere” (First, do no harm), is fundamental in medical ethics. While not explicitly stated in the original Hippocratic oath, it reflects the importance

of minimizing harm done to patients during treatment and prioritizing their well-being. To adhere to this properly, it is important to carefully consider which patients benefit from operative treatment and for whom nonoperative treatment is more suitable, without compromising patient-reported functional outcomes. Today, more than 60% of tibial plateau fractures are operatively treated aiming to achieve adequate fracture reduction, which reduces the risk of post-traumatic osteoarthritis and conversion to total knee arthroplasty [9,10]. However, there is growing awareness that nonoperative treatment might be a good alternative for some minimally displaced fractures resulting in fewer adverse events [11]. The current indication for operative treatment is an intra-articular gap and/or step-off above 2 mm, based on traditional studies from 30 years ago with measurements performed on plain radiographs [7,12,13]. This cut-off is still believed to be essential for achieving good functional outcomes, even though there is little evidence supporting this threshold [14]. In addition, initial fracture displacement is often underestimated when measurements are performed on plain radiographs [15]. Since clinical decision-making is nowadays primarily based on CT-scans, it is unclear if the current 2 mm cut-off is still justified, or whether it may be an underestimation of the actual displacement that can be accepted for nonoperative treatment. **Chapter 4** assessed if initial fracture displacement (i.e. gap and step-off) above and below this critical 2 mm cut-off, as measured on CT-scan images, resulted in different patient-reported functional outcomes in more than 200 nonoperatively treated patients. Results of this study showed no significant differences in functional outcome between patients with < 2 mm or 2-4 mm initial gap and/or step-off. For clinical practice, this indicates that more initial fracture displacement (i.e. gaps and step-offs up to 4 mm) can be accepted for nonoperative treatment, without compromising functional outcomes. However, there was no direct comparison made with patients who had operative treatment for their minimally displaced tibial plateau fractures. Therefore, in **Chapter 5**, the outcomes after both operative and nonoperative treatment of patients with gaps and step-offs up to 4 mm were compared. Results showed that operative treatment was not associated with better patient-reported outcomes at mid-term follow-up. In addition, operative treatment resulted in more complications and 39% needed a secondary intervention. Since there were no differences in functional outcome, nonoperative treatment should be the preferred treatment in minimally displaced tibial plateau fractures, especially considering the lower number of complications and reoperations. When consulting these patients regarding their treatment, it is important to carefully discuss the increased risks of operative treatment against benefits such as early mobilization. However, surgeons should be aware that operative treatment in patients with minimally displaced tibial plateau fractures (i.e. gaps and/or step-offs up to 4 mm) will not improve functional outcomes. When operative treatment is indicated, the general aim is to restore articular congruity, reestablish joint stability, and achieve normal axial and coronal alignment [9,10]. Radiographic measurements are

frequently performed to assess whether operative results are within the normal ranges. However, the actual impact of both initial fracture displacement and the achieved fracture reduction on patient-reported functional outcomes remains unknown, which makes it difficult to adequately counsel patients regarding expected outcomes. In **Chapter 6**, the association between initial fracture displacement, fracture reduction, tibial alignment and recovery in terms of patient-reported functional outcomes in operatively treated patients was assessed. Our findings revealed that severe initial fracture displacement (> 10 mm gap and/or > 8 mm step-off) was associated with increased odds of not reaching full recovery. This is most likely due to the substantial damage of cartilage and surrounding soft tissues caused by the impact during trauma. Since patients have high expectations regarding knee function and residual pain, it is important to explain that some of the initial damage is irreversible and cannot be undone by operative treatment [16]. Interestingly, our study showed no differences in outcome for residual displacement up to 4 mm, while displacement above 4 mm increased the odds of not reaching full recovery. This finding is consistent with the initial gap and step-off that can be accepted without affecting functional outcomes according to the previous chapters. Furthermore, inadequate postoperative tibial alignment (i.e. MPTA and PPTA) was associated with increased odds of not reaching full recovery. These results emphasize the importance of adequate fracture reduction and tibial alignment after operative treatment and can be used to consider whether reoperations are needed to improve outcomes. In conclusion, the second part of this thesis aimed to evaluate current treatment indications and why the type of treatment matters. Our studies added to the current knowledge by showing that surgeons should be aware that nonoperative treatment should be considered in tibial plateau fractures with gaps and/or step-off up to 4 mm. This minimizes the harm done to patients, since improved functional outcomes are not expected from operative treatment. Furthermore, it was shown that when operative treatment is necessary due to extensive fracture displacement, it is important to achieve adequate fracture reduction (< 4 mm incongruence) and tibial alignment (MPTA $87^\circ \pm 5^\circ$ and PPTA $9^\circ \pm 5^\circ$) to minimize the odds of not reaching full recovery during follow-up.

How do they recover

Tibial plateau fractures are known to have a major impact on patients and affect their ability to perform normal daily activities like playing sports or working. The most essential questions that patients have after sustaining these injuries are: How will I recover after my injury? How long will my recovery trajectory be before I can return to my normal daily activities? Will I be able to return to my previous level of physical functioning? However, most studies do not indicate to what extent patients recover after their tibial plateau fracture compared to their own pre-injury score. Even though many different factors are related to the functional outcome scores as described in previous chapters, the extent of

recovery provides important information for managing patients' expectations. In **Chapter 7**, functional outcome scores of patients with tibial plateau fractures were compared with normative scores of age-matched peers from the general population [17]. The results showed that nonoperatively treated patients generally have higher outcomes scores than those who had operative treatment. Although most patients regained sufficient function to perform daily activities, tibial plateau fractures had a significant impact on their ability to perform sports and their quality of life, and most patients did not return to the level of age-related peers. It appears that regardless of the treatment, a large portion of patients will never fully recover. However, since outcomes were compared with those of the general population, it remained uncertain to what extent patients recover relative to their own pre-injury scores. Also, their questions regarding the expected duration of the recovery trajectory remained unanswered as these outcomes were assessed at mid-term follow-up. In **Chapter 8**, a large prospective multicenter study was performed in all patients treated for their tibial plateau fracture, in which patient-reported functional outcomes at fixed time points (i.e. pre-injury, three months, six months and one year) during follow-up were obtained. Results showed that both operatively and nonoperatively treated patients had a steep decrease in functional outcome at three months compared to their pre-injury score, continued by a slow increase at six months and one year of follow-up. Nonoperatively treated patients reached 82% of their mean pre-injury KOOS score after one year and 40% was fully recovered. Operatively treated patients reached 64% of their mean pre-injury KOOS score after one year and only 14% was fully recovered. This was particularly pronounced in the subdomains of sports and quality of life, where the percentage of fully recovered patients was even lower. Furthermore, after the one year of follow-up, a substantial number of patients still experienced serious knee pain, difficulties with heavy domestic duties or running, and is consistently reminded of their knee problems. Unfortunately, as our results indicate, only a small group of patients has completely recovered after one year of follow-up. These findings emphasize the major impact of tibial plateau fractures on patients. Sustaining a tibial plateau fracture is not a short-term problem but has long-term effects on most of the patients. When consulting patients with tibial plateau fractures, it is therefore important to properly inform them about their poor prognosis [16]. This allows patients to create more realistic expectations regarding their course of recovery. In conclusion, the third part of this thesis aimed to get more insight in the patient-reported functional outcome and explore what patients can expect after their injury. Our studies added to the current knowledge by showing the extent to which patients recover after tibial plateau fractures and provided more insight into the domains where patients experience difficulties (e.g. sport). Furthermore, our prospective multicenter study with multiple measuring moments provided detailed information about the course of recovery within the first year. Tibial plateau fractures are serious injuries, and many patients never return to their pre-injury level or to the score of

age-related peers. These fractures often result in lifelong disability, and patients, surgeons, and healthcare providers should be aware of this long-term impact.

Future perspectives

Patient-reported outcome measures (PROMs) should become standard in the management of tibial plateau fractures. Systematical integration of these outcome measures into electronic patients' records enables continuous monitoring of the recover trajectory for each individual patient, which allows earlier clinical intervention, as treating physicians can identify deviations from expected recovery patterns, which indicate that patient's suboptimal progress in certain domains. Earlier interventions, such as additional (operative) treatment or more intensive guidance during rehabilitation, could be beneficial for these patients and potentially improve their functional outcomes. Moreover, by collecting these outcome measures, patients can monitor how their own course of recovery progresses. This enables patients to visualize whether their recovery is progressing as expected or if they perform above or below average. In this way, patients will become more involved in their own treatment, which will ultimately lead to higher levels of patient satisfaction. In a broader perspective, systematically collecting patient-reported outcome measures would allow the development of prediction models that could assist in future clinical decision making. These data driven models enable a more personalized treatment, as they can predict which treatment would be most beneficial to each individual patient. In addition, based on these models, treating physicians can create more realistic and personalized expectations regarding the expected recovery of individual patients. In future prospective studies including multiple measuring moments during follow-up, there should be more attention to the mental health of patients with these injuries, as they often have a major impact on their life.

Conclusion

The most important part of treatment in patients with tibial plateau fractures is how they will recover. This PhD thesis focused on patient-reported functional outcomes in all aspects of a tibial plateau fracture, from injury to treatment and, most importantly, recovery. In the first part it was showed that tibial plateau fractures require thorough initial examination. Identification of the injury mechanism provides important information regarding associated injuries and expected outcomes, which allows more patient specific treatment. In the second part it was demonstrated that patients with minimally displaced tibial plateau fractures benefit most from nonoperative treatment. The more severe fractures that need operative treatment require adequate fracture reduction and tibial alignment to minimize the odds of no full recovery. In the last part it was showed that tibial plateau fractures often have major long-lasting effects on patient-reported functional outcomes. When treating these patients, it is important to realize that sustaining a tibial plateau fracture is a life-changing event, as many of the patients never fully recover.

REFERENCES

1. Elsoe R, Larsen P, Nielsen NPH, Swenne J, Rasmussen S, Ostgaard SE. Population-based epidemiology of tibial plateau fractures. *Orthopedics*. 2015;38:e780–786.
2. Xie X, Zhan Y, Wang Y, Lucas JF, Zhang Y, Luo C. Comparative analysis of mechanism-Associated 3-Dimensional Tibial Plateau Fracture Patterns. *J Bone Joint Surg Am*. 2020;102:410–418.
3. Zhang BB, Sun H, Zhan Y, He QF, Zhu Y, Wang Y, et al. Reliability and repeatability of tibial plateau fracture assessment with an injury mechanism-based concept. *Bone Joint Res*. 2019;8:357–366.
4. Berkson EM, Virkus WW. High-energy tibial plateau fractures. *J Am Acad Orthop Surg*. 2006;14:20–31.
5. Gardner MJ, Yacoubian S, Geller D, et al. The incidence of soft tissue injury in operative tibial plateau fractures: a magnetic resonance imaging analysis of 103 Patients. *J Orthop Trauma*. 2005;19:79–84.
6. Thürig G, Korthaus A, Frosch KH, Krause M. The value of magnetic resonance imaging in the preoperative diagnosis of tibial plateau fractures: a systematic literature review. *Eur J Trauma Emerg Surg*. 2023;49:661–679.
7. Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. *EFORT Open Rev*. 2017;1:225–232.
8. Rozell JC, Vemulapalli KC, Gary JL, Donegan DJ. Tibial plateau fractures in elderly patients. *Geriatr Orthop Surg Rehabil*. 2016;7:126–134.
9. Assink N, Moumni M El, Kraeima J, et al. Radiographic predictors of conversion to total knee arthroplasty after tibial plateau fracture surgery results in a large multicenter cohort. *J Bone Joint Surg Am*. 2023;105:1237–1245.
10. Parkkinen M, Madanat R, Mustonen A, Koskinen SK, Paavola M, Lindahl J. Factors predicting the development of early osteoarthritis following lateral tibial plateau fractures: mid-term clinical and radiographic outcomes of 73 operatively treated Patients. *Scand J Surg*. 2014;103:256–262.
11. Skou ST, Juhl CB, Hare KB, Lohmander LS, Roos EM. Surgical or non-surgical treatment of traumatic skeletal fractures in adults: Systematic review and meta-analysis of benefits and harms. *Syst Rev*. 2020;9:179
12. Pelser P. Controversies in the management of tibial plateau fractures. *SA Orthopaedic Journal*. 2010;9:75–82.
13. Tscherné H, Lobenhoffer P. Tibia plateau fractures management and expected results. *Clin Orthop Relat Res*. 1993;292:87–100.
14. Marsh JL, Buckwalter J, Gelberman R, Dirschl D, Olson S, Brown T, et al. Articular Fractures: Does an anatomic reduction really change the result? *J Bone Joint Surg Am*. 2002;84:1259–1271.
15. Meesters AML, Ten Duis K, Banierink H, et al. What are the interobserver and intraobserver variability of gap and stepoff measurements in acetabular fractures? *Clin Orthop Relat Res*. 2020;478:2801–2808.
16. Keppler L, Keppler AM, Ihle C, Minzlaff P, Fürmetz J, Beck M, et al. Patients with complex proximal tibial fractures overestimate the prognosis of their injury. *Eur J Trauma Emerg Surg*. 2022;48:1479–1486.
17. Larsen P, Rathleff MS, Roos EM, Elsoe R. Knee injury and osteoarthritis outcome score (KOOS) – National record-based reference values. *Knee*. 2023;43:144–152.

Appendices



SUMMARY

The tibial plateau forms the lower part of the knee, which is one of the most weight-bearing joints in the body. Tibial plateau fractures account for 1-2% of all fractures and are among the most challenging injuries to treat due to the complex fracture morphology. They are known as fractures that have a major impact on the patient's life and their ability to perform daily activities like playing sports or working. Nevertheless, there is limited literature regarding the relationship between injury mechanisms, treatment, fracture characteristic (i.e. radiographic measurements) and functional outcomes. This lack of evidence makes it challenging to adequately counsel patients regarding their recovery and the potential need for conversion to total knee arthroplasty. Therefore, the overall aim of the research in this thesis was to get more insight in the patient-reported functional outcomes after tibial plateau fractures. This thesis covers most aspects of the injury — from the initial trauma to recovery — and is divided into three parts: (1) How do they occur, (2) How are they treated, and (3) How do they recover.

How do they occur

Tibial plateau fractures are caused by both high- and low-energy traumas, which range from relatively simple low-energy falls, such as tripping over a sidewalk, to more severe high-energy incidents like motorcycle crashes. Besides damage to the tibial plateau, which is caused by varus or valgus forces combined with axial load, these fractures are also associated with severe trauma of the surrounding soft tissues. Understanding the different impact of these high- and low-energy trauma mechanisms allows to adequately counsel patients regarding their prognosis. **Chapter 2** reported on differences in patient characteristic and clinical outcomes after high- and low-energy trauma. Results showed that 12% of all tibial plateau fractures were caused by high-energy trauma, predominantly in younger males. High-energy traumas resulted in more extended fracture patterns and slightly worse patient-reported functional outcomes. There was no substantial difference in conversion to total knee arthroplasty (TKA). However, since high-energy traumas primarily occur in younger patients for whom surgeons are more conservative in recommending TKA, the high conversion rate highlights the severity of these injuries. In elderly patients, low-energy trauma can still result in severe Schatzker VI fractures, most likely due to the higher prevalence of osteoporosis. Nevertheless, surgeons should be aware that treatment of high-energy trauma patients is challenging as they have a higher risk of complications and worse outcomes during follow-up. Besides the amount of energy during trauma causing different types of tibial plateau fractures, these fractures are also characterized by six unique fracture patterns, created by the position of the leg and the direction of force during the injury. Even though these unique fracture patterns have been identified, it remains unknown to what extent they are associated with functional outcomes. **Chapter 3** assessed the association between these unique fracture patterns and functional outcomes.

Results showed that particularly fractures which were caused by varus-flexion forces resulted in worse patient-reported functional outcomes, were associated with increased risks of conversion to TKA and needed more reoperations for soft tissue repair. Our findings suggest that especially patients with tibial plateau fractures caused by varus-flexion forces should more often undergo MRI to assess the extent of associated soft tissue injury. This enables the surgeon to be prepared and address these injuries during surgery.

How are they treated

To adhere to the principle “Primum non nocere” (First, do no harm), it is important to carefully consider whether patients benefit more from operative or nonoperative treatment without compromising patient-reported functional outcomes. The traditional radiographic based indication for operative treatment is an intra-articular gap and/or step-off above 2 mm. However, as clinical decision-making is now primarily based on CT-scans, it is unclear whether this 2 mm cut-off is still justified or an underestimation of the actual displacement that can be accepted for nonoperative treatment. **Chapter 4** assessed if nonoperative treatment of patients with initial gaps and/or step-offs slightly above 2 mm resulted in worse patient-reported functional outcomes compared to patients with gaps and/or step-offs below 2 mm. Results showed no differences in functional outcome between patients with initial fracture displacement below 2 mm and those with 2–4 mm, indicating that gaps and/or step-offs up to 4 mm can be accepted for nonoperative treatment and likely result in good patient-reported outcomes at mid-term follow-up. However, no direct comparison was made with patients who had operative treatment for their minimally displaced tibial plateau fractures. **Chapter 5** assessed outcomes after operative versus nonoperative treatment of patients with gaps and/or step-offs up to 4 mm. This study showed no significant differences in patient-reported functional outcomes at mid-term follow-up, regardless the type of treatment. Furthermore, operative treatment resulted in more complications (e.g. fracture-related infections, peroneal nerve neurapraxia) and 39% needed a secondary intervention of which 36% was due to elective implant removal. These findings suggest that nonoperative treatment should be the preferred treatment in minimally displaced tibial plateau fractures, especially considering the lower number of complications and reoperations. Although operative treatment has potential benefits such as early mobilization, surgeons should be aware that operative treatment in patients with minimally displaced tibial plateau fractures (i.e. gaps and/or step-offs up to 4 mm) will likely not improve functional outcomes. When operative treatment is indicated in more severely displaced fractures, the aim is to restore articular congruity, reestablish joint stability and achieve normal coronal and sagittal alignment. Radiographic measurements are frequently used to assess initial and residual fracture displacement and tibial alignment, even though the actual impact of these measurements on patient-reported outcome is unknown. This makes it difficult to adequately counsel

patients regarding expected outcomes. **Chapter 6** assessed the association between initial and residual fracture displacement, tibial alignment and recovery in terms of patient-reported functional outcomes. Results showed that gaps > 10 mm and step-offs > 8 mm were associated with increased odds of not reaching full recovery regardless of fracture reduction, which indicates that some of the initial damage is irreversible. Furthermore, residual fracture displacement above 4 mm and inadequate coronal and sagittal alignment were associated with increased odds of not reaching full recovery. These findings emphasize the importance of adequate fracture reduction and tibial alignment, which can be used for considering reoperations to improve outcomes.

How do they recover

Tibial plateau fractures are known to have a major impact on patients and their ability to perform daily activities. The essential questions that patients have after these injuries are: How will I recover after my injury? How long will it take before I can return to my daily activities? Will I return to my previous level of physical functioning? Yet, most studies do not indicate to what extent patients recover compared to their own pre-injury score, which is important as it provides information for managing patients' expectations.

Chapter 7 compared functional outcome scores of patients with tibial plateau fractures with normative (e.g. reference) scores of age-matched peers from the general population. The results showed that nonoperatively treated patients generally have higher outcome scores than those who had operative treatment. Most patients regained sufficient function to perform daily activities, but tibial plateau fractures had a significant impact on their ability to play sports and their quality of life, as most patients did not return to the level of age-related peers. However, since outcomes were compared with the general population, the level of recovery relative to patients own pre-injury scores remained uncertain.

Chapter 8 assessed the course of recovery of patients after sustaining a tibial plateau fracture in a large prospective multicenter study where functional outcomes were obtained at fixed time points (pre-injury, three months, six months and one year) during follow-up. Results showed for both operatively and nonoperatively treated patients a steep decrease in functional outcome at three months compared to their pre-injury score, continued by a slow increase at six months and one year. Nonoperatively treated patients reached 82% of their mean pre-injury KOOS score after one year and 40% was fully recovered. Operatively treated patients reached 64% of their mean pre-injury KOOS score after one year and 14% was fully recovered. Furthermore, many patients continued to experience serious knee pain, difficulties with heavy domestic duties or running and were consistently reminded of their knee issues even at one-year follow-up. These findings provide insight into the impact of tibial plateau fractures on patients and show it is not short-term problem but cause long-term effects on most patients. It is important to inform patients about their prognosis and create realistic expectations regarding their recovery journey.

Future perspectives

Patient-reported outcome measures (PROMs) should become standard in the management of tibial plateau fractures. Systematical integration of these measures into electronic patient records enables continuous monitoring of each patient's recover trajectory. Treating physicians can identify deviations from expected recovery patterns, which allows for earlier clinical intervention, such as additional treatment or more intensive rehabilitation guidance, and offers the potential to improve functional outcomes. Moreover, patients can monitor their own recovery trajectory and visualize whether their recovery is progressing as expected. In a broader perspective, the collected data allows development of prediction models to assist in clinical decisions such as treatment choice, and to create personalized recovery expectations. Future prospective studies should consider including mental health as a factor, since these injuries often have a major impact on the patient's life.

Conclusion

This thesis focused on patient-reported functional outcomes throughout the patient journey of tibial plateau fracture treatment, from injury to treatment and, most importantly, recovery. The first part showed that tibial plateau fractures require thorough initial assessment of the injury mechanism, fracture pattern and direction of forces during injury, as they provide important information about potential associated injuries and expected outcomes, allowing for patient specific treatment. The second part showed that patients with minimally displaced tibial plateau fractures benefit most from nonoperative treatment, while more severe fractures require adequate operative fracture reduction and tibial alignment to enhance the odds of full recovery. The third part showed the course of recovery and long-lasting effects on functional outcomes after tibial plateau fractures. Although patients regain sufficient function for daily activities, it significantly impacts their ability to perform sports. These fractures can be life-changing injuries as many patients never achieve full recovery.

SAMENVATTING

Het tibiaplateau vormt het onderste deel van de knie, wat een van de meest gewichtsdragende gewrichten in het lichaam is. Tibiaplateau fracturen vormen 1 tot 2% van alle fracturen en behoren tot de meest uitdagende letsels om te behandelen vanwege de complexe fractuurmorfologie. Deze fracturen kunnen grote impact hebben op het leven van een patiënt en diens vermogen om dagelijkse activiteiten zoals sporten of werk weer op te pakken. Desondanks is er weinig literatuur over de relatie tussen ongevalsmechanismen, behandelingen, fractuurkarakteristieken (zoals radiografische metingen) en functionele uitkomsten. Hierdoor is het lastig om patiënten adequaat te informeren over hun herstel en de kans dat zij in de toekomst een knieprothese nodig zullen hebben. Het doel van het onderzoek in dit proefschrift was dan ook meer inzicht te krijgen in door patiënt gerapporteerde functionele uitkomsten na een tibiaplateau fractuur. Dit proefschrift belicht het hele traject van deze letsels — van het initiële trauma tot aan het herstel — en is opgedeeld in drie delen: (1) Hoe ontstaan ze, (2) Hoe worden ze behandeld, en (3) Hoe herstellen ze.

Hoe ontstaan ze

Tibiaplateau fracturen worden veroorzaakt door zowel hoogenergetische als laag energetische trauma's, variërend van een relatief simpele val, zoals struikelen over een stoeprand, tot ernstigere hoogenergetische incidenten, zoals een motorongeval. Naast schade aan het tibiaplateau, die wordt veroorzaakt door varus of valgus krachten in combinatie met axiale belasting, gaan deze fracturen vaak gepaard met ernstig letsel van de omliggende weke delen. Het is daarom belangrijk om de verschillen tussen hoogenergetische en laag energetische trauma's te begrijpen, zodat patiënten adequaat geïnformeerd kunnen worden over hun prognose. **Hoofdstuk 2** beschrijft de verschillen in patiëntkenmerken en klinische uitkomsten na hoogenergetische en laag energetische trauma's. De resultaten toonden aan dat 12% van alle tibiaplateau fracturen werd veroorzaakt door een hoogenergetisch trauma, overwegend bij jongere mannen. Hoogenergetische trauma's resulteerden in uitgebreide fractuurpatronen en iets slechtere patiëntgerapporteerde functionele uitkomsten. Er was geen substantieel verschil in de conversie naar een totale knieprothese (TKP). Echter, doordat hoogenergetische trauma's vooral bij jongere patiënten voorkomen, bij wie chirurgen veelal terughoudend zijn met het adviseren van een TKP, onderstreept het relatief hoge conversiepercentage de ernst van deze letsels. Bij oudere patiënten kan ook een laag energetisch trauma tot een ernstige Schatzker VI-fractuur leiden, waarschijnlijk door de hogere prevalentie van osteoporose in deze groep. Desondanks moeten chirurgen zich ervan bewust zijn dat de behandeling van patiënten met een hoogenergetisch trauma een uitdaging is, doordat zij een hoger risico op complicaties en minder goede uitkomsten hebben op langere termijn. Tibiaplateau fracturen onderscheiden zich niet alleen in type, veroorzaakt door het energetische niveau

van het trauma, maar worden ook gekenmerkt door zes unieke fractuurpatronen, die worden veroorzaakt door de stand van het been en de richting van de impact tijdens het ongeval. Hoewel deze unieke fractuurpatronen zijn geïdentificeerd, is het nog onbekend in hoeverre ze samenhangen met functionele uitkomsten. **Hoofdstuk 3** belicht de relatie tussen de unieke fractuurpatronen en de functionele uitkomsten. De resultaten toonden aan dat vooral fracturen die veroorzaakt waren door varus-flexie krachten gepaard gingen met slechtere patiëntgerapporteerde functionele uitkomsten. Deze fracturen leidden bovendien vaker tot conversie naar TKP en meer heroperaties voor het herstel van weke delen. Onze bevindingen suggereren dat bij patiënten met een tibiaplateau fractuur die is veroorzaakt door varus-flexie krachten vaker een MRI gemaakt moet worden om de omvang van het letsel aan de weke delen in kaart te brengen, zodat de chirurg voorbereid is en deze letsels meteen tijdens de operatie kan behandelen.

Hoe worden ze behandeld

Om het principe “Primum non nocere” (“Eerst, geen schade toebrengen”) te waarborgen, is het belangrijk zorgvuldig af te wegen of patiënten meer baat hebben bij een operatieve of juist conservatieve behandeling, zonder dat dit gevolgen heeft voor de patiëntgerapporteerde functionele uitkomsten. De traditionele indicatie voor een operatie is een intra-articulaire gap en/of step-off van meer dan 2 mm, welke is gebaseerd op röntgenfoto's. Omdat klinische beslissingen tegenwoordig vooral worden gebaseerd op CT-scans, is het onduidelijk of deze grens van 2 mm nog steeds gerechtvaardigd is of dat dit misschien een onderschatting is van de daadwerkelijke fractuurverplaatsing die kan worden geaccepteerd voor een conservatieve behandeling. **Hoofdstuk 4** onderzocht of een conservatieve behandeling van patiënten met een initiële gap en/of step-off van net boven de 2 mm resulteerde in slechtere functionele uitkomsten in vergelijking met patiënten met een gap en/of step-off van onder de 2 mm. De resultaten toonden geen verschil in de functionele uitkomsten tussen patiënten met een initiële fractuurverplaatsing onder de 2 mm en die met een verplaatsing tussen de 2 en 4 mm, waaruit bleek dat een gap en/of step-off tot 4 mm (gemeten op CT-scans) acceptabel is voor een conservatieve behandeling en naar verwachting goede uitkomsten geeft op middellange termijn. Er werd in dit hoofdstuk echter geen directe vergelijking gemaakt met patiënten die een operatie ondergingen voor minimaal gedислоceerde tibiaplateau fracturen. **Hoofdstuk 5** presenteert de uitkomsten na een operatieve versus niet-operatieve behandeling van patiënten met een gap en/of step-off tot 4 mm. Deze studie liet geen significante verschillen zien in functionele uitkomsten op de middellange termijn, ongeacht de gekozen behandeling. Verder bleek dat een operatieve behandeling in meer complicaties resulteerde (zoals fractuur gerelateerde infecties of peroneus neuropathie) en 39% een secundaire ingreep nodig had, waarvan 36% voor electieve verwijdering van het implantaat. Deze bevindingen suggereren dat een niet-operatieve behandeling de voorkeur heeft bij minimaal gedислоceerde tibiaplateau

fracturen, zeker gezien het lagere aantal complicaties en heroperaties. Hoewel een operatie voordelen kan bieden, zoals sneller mobiliseren, moeten chirurgen zich realiseren dat een operatie van minimaal gedислоceerde tibiaplateau fracturen (met een gap en/of step-off tot 4 mm) waarschijnlijk niet zal resulteren in betere functionele uitkomsten. Wanneer een operatie wel geïndiceerd is, zoals bij ernstigere en meer gedислоceerde fracturen, is het doel het herstellen van het gewrichtsooppervlak, het creëren van stabiliteit en het bereiken van een normale coronale en sagittale beenas. Veelal worden radiografische metingen gebruikt om de initiële en resterende disclocatie van de fractuur en stand van de tibia te beoordelen, hoewel de impact van deze metingen op de patiëntgerapporteerde functionele uitkomsten niet bekend is. Dit maakt het lastig om patiënten adequaat te informeren over de verwachte uitkomsten. **Hoofdstuk 6** onderzocht het verband tussen de initiële en resterende fractuurverplaatsing, stand van de tibia en het herstel, gemeten door middel van patiëntgerapporteerde functionele uitkomsten. Uit de resultaten bleek dat gaps > 10 mm en step-offs > 8 mm geassocieerd werden met een verhoogde kans op het niet bereiken van volledig herstel, ongeacht de mate van fractuurreductie tijdens de operatie. Dit wijst erop dat een deel van de initiële schade onomkeerbaar is. Daarnaast wordt een resterende fractuurverplaatsing van meer dan 4 mm en inadequate coronale en sagittale uitlijning geassocieerd met een verhoogde kans op onvolledig herstel. Deze bevindingen benadrukken het belang van een adequate fractuurreductie en uitlijning van de beenas. Deze inzichten kunnen worden gebruikt voor het afwegen van eventuele heroperaties ter verbetering van de uitkomst.

Hoe verloopt het herstel

Tibiaplateau fracturen hebben een grote impact op patiënten en hun vermogen om dagelijkse activiteiten uit te voeren. De belangrijkste vragen die patiënten na dit letsel hebben zijn: Hoe herstel ik van dit letsel? Hoelang duurt het voor ik mijn dagelijkse activiteiten weer kan uitvoeren? Kom ik weer terug op mijn oude niveau van functioneren? Toch geven de meeste studies niet aan in hoeverre patiënten herstellen ten opzichte van het niveau dat zij hadden voor het ongeval, terwijl dit belangrijke informatie geeft over wat een patiënt kan verwachten tijdens de revalidatie. **Hoofdstuk 7** vergeleek functionele uitkomsten van patiënten met een tibiaplateau fractuur met referentiewaarden van leeftijdsgenoten uit de algemene bevolking. De resultaten lieten zien dat conservatief behandelde patiënten gemiddeld hogere uitkomstscores hadden dan geopereerde patiënten. De meeste patiënten kregen voldoende functie terug om hun dagelijkse activiteiten weer uit te voeren. Toch hadden tibiaplateau fracturen significante impact op het vermogen tot sporten en de kwaliteit van leven, aangezien de meeste patiënten niet terugkeerden naar het niveau van functioneren van hun leeftijdsgenoten. Echter doordat de uitkomsten werden vergeleken met die van de algemene bevolking, blijft het onduidelijk hoe het herstel zich verhoudt tot het eigen niveau van functioneren van de patiënt voor

het ongeval. **Hoofdstuk 8** gaat in op het verloop van het herstel bij patiënten na een tibiaplateau fractuur in een grote prospectieve multicenterstudie, waarbij functionele uitkomsten op vaste momenten tijdens de follow-up werden gemeten (voor het letsel, na drie maanden, na zes maanden en na een jaar). Uitkomsten lieten zien dat, zowel bij operatief als conservatief behandelde patiënten, er een sterke daling was in functionele uitkomsten na drie maanden ten opzichte van voor het ongeval, gevolgd door een geleidelijke verbetering bij zes en twaalf maanden. Conservatief behandelde patiënten bereikten na een jaar 82% van hun gemiddelde niveau van voor het ongeval en 40% was volledig hersteld. Geopereerde patiënten bereikten na een jaar 64% van hun gemiddelde niveau van voor het ongeval en 14% was volledig hersteld. Veel patiënten bleven de nodige klachten houden zoals kniepijn of moeite met zwaar huishoudelijk werk of hardlopen, en werden zelfs na een jaar nog voortdurend herinnerd aan hun knieproblemen. Deze bevindingen geven inzicht in de impact van tibiaplateau fracturen en tonen aan dat het herstel veelal een langdurig traject is en dat de meeste patiënten langdurig klachten blijven houden. Het is belangrijk patiënten goed te informeren over hun prognose en realistische verwachtingen te scheppen over hun herstelproces.

Toekomstperspectief

Patiëntgerapporteerde uitkomsten (PROMs) zouden standaard moeten worden afgenomen bij de behandeling van tibiaplateau fracturen. Door deze uitkomsten systematisch te integreren in het elektronisch patiëntendossier kan het hersteltraject van elke patiënt continu gevolgd worden. Behandelend artsen kunnen daarbij afwijkingen van het verwachte herstelpatroon vroegtijdig signaleren, wat tijdige aanvullende behandelingen of intensievere revalidatie mogelijk maakt en zo de functionele uitkomst kan verbeteren. Ook kunnen patiënten hun eigen herstel monitoren en zien of het herstel verloopt zoals verwacht. In bredere zin stelt de verzamelde data ons in staat predictiemodellen te ontwikkelen, bijvoorbeeld ter ondersteuning van klinische besluitvorming, zoals de keuze voor behandeling en het opstellen van een gepersonaliseerd verwachtingspatroon. In toekomstige studies zou er ook meer aandacht moeten komen voor de mentale gezondheid, omdat deze letsels vaak een grote impact hebben op het leven van de patiënt.

Conclusie

Dit proefschrift richtte zich op patiëntgerapporteerde functionele uitkomsten gedurende het gehele behandeltraject van tibiaplateau fracturen, van het ongeval tot de behandeling en, als belangrijkste, het herstel. Het eerste deel liet zien dat tibiaplateau fracturen een grondige initiële beoordeling van het ongevalsmechanisme, het fractuurpatroon en de richting van de impact tijdens het ongeval vereisen. Dit levert belangrijke informatie op over mogelijke bijkomende letsels en de te verwachten uitkomsten, zodat een patiënt specifieke behandeling kan worden gekozen. Het tweede deel toonde aan dat patiënten

met minimaal gedisloceerde tibiaplateau fractures het meeste baat hebben bij een niet-operatieve behandeling, terwijl de ernstigere fractures juist een adequate operatieve fractuurreductie en uitlijning vereisen om de kans op volledig herstel te vergroten. Het derde deel beschrijft het herstelverloop en de langdurige gevolgen voor de functionele uitkomst na een tibiaplateau fractuur. Hoewel patiënten voldoende functie terugkrijgen voor het uitvoeren van dagelijkse activiteiten, heeft het letsel een aanzienlijke impact op het vermogen om te sporten. Deze fractures kunnen levensveranderende letsels zijn, waarvan veel patiënten nooit volledig herstellen.

DANKWOORD

Het afronden van mijn proefschrift betekent ook het einde van een bijzondere periode. Dit was niet mogelijk geweest zonder de begeleiding, samenwerking en steun van anderen. Graag wil ik dan ook iedereen bedanken die, op wat voor manier dan ook, hieraan heeft bijgedragen. Naast alle patiënten die aan de verschillende onderzoeken in dit proefschrift deelnamen, wil ik graag een aantal personen in het bijzonder bedanken.

Dr. Ijpma, beste Frank, ik kan mij nog goed herinneren hoe dit alles tot stand is gekomen na onze eerste kennismaking, waarbij ik vertelde dat ik graag onderzoek wilde doen bij de traumachirurgie. Wat op de operatiekamer begon als idee voor een eerste studie, groeide uit tot een prachtig onderzoeksplan. Jouw enthousiasme voor traumachirurgie en onderzoek werkte aanstekelijk en heeft mij enorm gemotiveerd. Bedankt voor alle steun die je hebt geboden, de tijd die je hebt geïnvesteerd en voor het vertrouwen dat je in mij hebt gesteld. Het was een fantastische periode waarin ik veel mooie, leerzame, gezellige en onvergetelijke momenten heb beleefd, niet alleen tijdens het onderzoek, maar ook daarbuiten. Ik had mij geen betere supervisor kunnen wensen en kijk ernaar uit om onze samenwerking in de komende jaren voort te zetten.

Dr. Assink, beste Nick, al vanaf het begin ben jij nauw betrokken geweest bij mijn onderzoek, eerst als medepromovendus en inmiddels als copromotor. Je goede ideeën, andere kijk op dingen en creativiteit om onze bevindingen vorm te geven, zijn een waardevolle bijdrage geweest waar ik veel van heb geleerd. In de afgelopen jaren hebben we tijdens het onderzoek veel mooie dingen beleefd, zoals onze bezoeken aan Leuven, verschillende congressen en op het terras waar veel nieuwe ideeën zijn ontstaan. Graag wil ik je bedanken voor alle steun, betrokkenheid en gezellige momenten gedurende deze periode die veel voor mij hebben betekend.

Prof. dr. Doornberg, beste Job, bedankt voor de vrijheid en het vertrouwen dat je Frank, Nick en mij hebt gegeven om de studies van mijn promotietraject vorm te geven. Naast je bijdrage aan mijn onderzoek wil ik je ook graag bedanken voor alles wat je daarbuiten mogelijk hebt gemaakt. Je enthousiasme om nieuwe dingen op te zetten, anderen erbij te betrekken en kennis te delen, hebben er onder andere voor gezorgd dat ik een prachtig Traumaplatform congres kon organiseren. Bedankt voor alle leerzame en mooie momenten die een waardevolle aanvulling waren op de afgelopen periode.

Geachte leden van de beoordelingscommissie, **prof. dr. M.H.J. Verhofstad**, **prof. dr. T.C. Kwee**, **prof. dr. C.K. van der Sluis**, graag wil ik u hartelijk danken voor de tijd en energie die u heeft gestoken in het bestuderen en beoordelen van dit proefschrift.

Graag wil ik ook alle medeauteurs van de artikelen bedanken voor hun waardevolle bijdrage. In het bijzonder gaat mijn dank uit naar de auteurs van het Martini, Isala, Gelre, MST en UZ Leuven. **Dr. Bosma**, **dr. van Helden**, **dr. Nijveldt**, **dr. van der Sluis**,

dr. ten Brinke, drs. de Groot en prof. dr. Hoekstra, dank voor jullie betrokkenheid en samenwerking. Zonder jullie was het niet mogelijk geweest om zo veel retrospectieve data voor alle onderzoeken te verzamelen. Daarnaast wil ik graag een aantal auteurs en collega's van het UMCG bedanken. **Prof. dr. De Vries, drs. Hogervorst, dr. ten Duis, dr. El Moumni, dr. Reininga, drs. Kramer en drs. Kraai**, dank voor de fijne samenwerking in de afgelopen jaren. Door jullie belangstelling en betrokkenheid is het mogelijk geweest om meerdere mooie onderzoeken te realiseren.

Ook wil ik graag iedereen bedanken die het mogelijk heeft gemaakt om de **PROTIB-studie**, een grote prospectieve multicenter studie, op te zetten. In het bijzonder gaat mijn dank daarbij uit naar de collega's van het UMCG, Martini, Isala, Frisius MC en Gelre. **Dr. Ijpma, dr. Assink, prof. dr. Doornberg, mw. van der Linden, dr. Bosma, dr. Damude, dr. Westerduin, dr. Nijveldt, dr. van der Linde, drs. Douma, drs. Munzebrock, dr. Rozema, dr. ten Brinke, dr. van der Werf en dhr. van Leur**, dank voor de fijne samenwerking in de afgelopen jaren bij deze studie. Zonder jullie betrokkenheid en inzet was het nooit mogelijk geweest om zo veel patiënten te includeren voor deze prospectieve database.

Medeonderzoekers en collega's uit het UMCG, beste **Jasper, Angad, Jonathan, Koen, Camryn en Lotte**, graag wil ik jullie bedanken voor alle gezelligheid op het werk, tijdens borrels en op de congressen. Zonder jullie waren de afgelopen jaren tijdens mijn onderzoeksperiode niet hetzelfde geweest. Daarnaast wil ik **Lotte** in het bijzonder bedanken voor haar betrokkenheid en inzet tijdens mijn onderzoek en het voortzetten van de PROTIB-studie. Ook wil ik graag de collega's van het 3D lab bedanken, waar ik altijd terecht kon voor een praatje en een goede kop koffie.

Traumaplatform, beste **Frederique, Lisa, Louise, Maaïke, Melle, Myrthe en Sophie**, tijdens mijn PhD heb ik samen met jullie in 2024 het Traumaplatform congres mogen organiseren. Dit heeft geresulteerd in een prachtige editie in het zonnige Toscane, waar nog lang over gesproken zal worden. Graag wil ik jullie bedanken voor alle gezelligheid tijdens onze vaste vergaderingen en natuurlijk tijdens de reis zelf. Het was een fantastische periode en een onvergetelijke aanvulling naast mijn onderzoek. Hopelijk tot de volgende editie.

Fortis et Liber, beste **Arjan, Bart, Gijs, Harwin, Jelmer, Jeroen, Joost, Klaas, Kor, Mitchel en Rob**, wat begon als een kennismaking op de borrels bij Gyas, leidde tot het vormen van een roeiploeg en is uitgegroeid tot een fantastische groep vrienden. In de afgelopen jaren hebben wij onvergetelijke momenten beleefd in de boot, tijdens vakanties, op ploegavonden en natuurlijk op de borrel of in de kroeg. Naast dat ik van jullie de bijnaam 'Kapitein' kreeg, werd ik door jullie ook de 'Eeuwige student' genoemd, iets waar met het afronden van mijn PhD een eind aan lijkt te zijn gekomen. Graag wil ik jullie allemaal bedanken voor deze onvergetelijke jaren en ik hoop dat er nog vele mogen volgen.

Beste **Laurens, Eeuwe** en **Jurjen**, onze vriendschap betekent veel voor mij. Ondanks dat we elkaar soms langere tijd niet zien, voelt het altijd als vanouds op het moment dat we elkaar weer treffen. Ik waardeer de goede gesprekken, de leuke dingen die we samen hebben ondernomen en de bijzondere momenten die we hebben beleefd. Graag wil ik jullie bedanken voor alles en ik kijk ernaar uit om nog veel meer mooie herinneringen met jullie te maken.

Paranimfen, beste **Jasper** en **Angad**, bedankt dat jullie tijdens de verdediging aan mijn zijde willen staan. **Jasper**, het blijft bijzonder dat we elkaar tijdens het onderzoek weer zijn tegengekomen, nadat we na de basisschool ieder een ander pad op gingen. Sindsdien hebben we een mooie vriendschap opgebouwd waar ik veel waarde aan hecht. **Angad**, wat begon met een kennismaking tijdens een researchmeeting in het UMCG, resulteerde in een waardevolle vriendschap. Ik wil jullie allebei bedanken voor jullie steun en betrokkenheid gedurende mijn onderzoek en voor alle gezellige en onvergetelijke momenten daarbuiten. De vele etentjes en avonden in de stad tot ons jaarlijkse bezoek aan de traumadagen had ik niet willen missen. Ik hoop dat we in de toekomst nog vele mooie herinneringen mogen toevoegen.

Geert, Dianne, Sybolt, Muriël, Maarten, Louise en **Teun**, familie van Anna, vanaf het begin heb ik me altijd welkom gevoeld bij jullie, wat ik enorm waardeer. Graag wil ik jullie dan ook bedanken voor alle gezelligheid, belangstelling en steun in de afgelopen jaren tijdens mijn promotietraject, maar ook daarbuiten.

Lieve **mama**, ik weet niet beter dan dat jij altijd het vertrouwen hebt gehad dat het goed zou komen met mij. Je staat altijd voor mij klaar en hebt mij van jongs af aan aangemoedigd om door te zetten en in mezelf te geloven. Dank je wel voor alles wat je voor mij hebt gedaan en nog steeds doet, voor je geduld, je luisterend oor en je eindeloze betrokkenheid. Dit betekent veel voor mij. Zonder jouw steun was ik nooit zo ver gekomen. Lieve **Lot** en **Roos**, mijn grote en kleine zus, dank jullie wel voor alle gezelligheid en voor jullie onvoorwaardelijke steun. Ik kon altijd op jullie rekenen, wat eraan heeft bijgedragen dat ik zo ver ben gekomen. Ik ben trots op jullie. **Peter, Daniël, Bart** en **Job**, ook jullie wil ik graag bedanken. Niet alleen omdat jullie er altijd voor mijn moeder en zusjes zijn, maar ook voor al jullie interesse en betrokkenheid.

Lieve **Anna**, ten slotte wil ik jou bedanken voor je onvoorwaardelijke steun, je geduld en de liefde die je me hebt gegeven. Bedankt dat je altijd naar mijn eindeloze verhalen over mijn werk luisterde en mij wist te motiveren als het even tegenzat. Ik weet dat mijn hoofd vaak bij het onderzoek zat, ook als we samen waren. Dankjewel dat je altijd voor mij klaarstond, veel taken van me hebt overgenomen en mij de ruimte hebt gegeven om dit proefschrift af te ronden, ook als ik weer eens tot diep in de nacht doorwerkte. Naast alles wat je voor mij hebt gedaan, ben ik ontzettend trots op jou, op je doorzettingsvermogen en de manier waarop je jouw eigen doelen najaagt. Ik kijk vol verwachting uit naar wat de toekomst ons gaat brengen.

LIST OF PUBLICATION

Vaartjes, T.P., Bosma, E., van Helden, S.H., ten Brinke, J.G., de Groot, R., Reininga, I.H.F., Doornberg, J.N., Hoekstra, H., Assink, N., IJpma, F.F.A. (2026). What Is the Association Between Radiographic Measurements of Initial and Residual Fracture Displacement, Tibial Alignment, and Recovery in Terms of Patient-reported Outcome After Surgical Treatment of Tibial Plateau Fractures? *Clinical Orthopaedics and Related Research*, 484(3), 520-529.

Vaartjes, T.P., van der Sluis, F.J., Bosma, E., ten Brinke, J.G., de Groot, R., Doornberg, J.N., Hoekstra, H., IJpma, F.F.A., Assink, N. (2025). Most patients with tibial plateau fractures regain function for daily activities but do not return to their pre-injury level of sport: comparison of multicenter cohort of 1101 patients and age-related peers. *European journal of trauma and emergency surgery*, 51(1), 285.

Vaartjes, T.P., Kraai, T.W., Bosma, E., van der Sluis, F.J., ten Brinke, J.G., de Groot, R., Hoekstra, H., Doornberg, J.N., Assink, N., IJpma, F.F.A. (2025). What is the patient-reported outcome, complication rate and conversion to total knee arthroplasty in patients with tibial plateau fractures caused by high-energy compared to low-energy mechanisms of injury? *European journal of trauma and emergency surgery*, 51(1), 160.

van der Linden, L.R., **Vaartjes, T.P.**, Kramer, C.J.S.A., Hoekstra, H., Doornberg, J.N., Assink, N., IJpma, F.F.A. (2025). What is the impact of the fracture location on patient-reported functional outcomes in patients with lateral tibial plateau fractures?. *Injury*, 56(11), 112720.

Assink, N., **Vaartjes, T.P.**, Kramer, C.J.S.A., Bosma, E., Nijveldt, R.J., ten Brinke, J.G., de Groot, R., Hoekstra, H., IJpma, F.F.A. (2024). What Is the Patient-reported Outcome and Complication Incidence After Operative Versus Nonoperative Treatment of Minimally Displaced Tibial Plateau Fractures?. *Clinical orthopaedics and related research*, 482(10), 1744–1752.

Assink, N., **Vaartjes, T.P.**, Bosma, E., van Helden, S.H., ten Brinke, J.G., Hoekstra, H., IJpma, F.F.A. (2024). Tibial plateau fracture morphology based on injury force mechanism is predictive for patient-reported outcome and conversion to total knee arthroplasty. *European journal of trauma and emergency surgery*, 50(3), 1135–1143.

Assink, N., El Moumni, M., Kraeima, J., Bosma, E., Nijveldt, R.J., van Helden, S.H., **Vaartjes, T.P.**, ten Brinke, J.G., Witjes, M.J.H., de Vries, J.P.M., IJpma, F.F.A. (2023). Radiographic Predictors of Conversion to Total Knee Arthroplasty After Tibial Plateau Fracture Surgery: Results in a Large Multicenter Cohort. *The Journal of bone and joint surgery*, 105(16), 1237–1245.

Vaartjes, T.P., Assink, N., Nijveldt, R.J., van Helden, S.H., Bosma, E., El Moumni, M., Duis, K.T., Hogervorst, M., Doornberg, J.N., de Vries, J.P.M., Hoekstra, H., IJpma, F.F.A. (2022). Functional Outcome After Nonoperative Management of Tibial Plateau Fractures in Skeletally Mature Patients: What Sizes of Gaps and Stepoffs Can be Accepted? *Clinical orthopaedics and related research*, 480(12), 2288–2295.

ABOUT THE AUTHOR

Thijs Pieter Vaartjes was born on April 21st, 1995 in Emmen. After completing his secondary education at Esdal College Emmen in 2014, he began studying Medical Imaging and Radiotherapeutic Techniques at the Hanze University of Applied Sciences in Groningen. Between 2014 and 2018, he followed the dual study program in which he combined his study with work. As a result, he moved to Apeldoorn in 2015 to work in the Department of Radiology and Nuclear Medicine at Gelre Hospitals Apeldoorn and Zutphen. During his study, he developed his strong interest in medicine, particularly in surgery. This motivated him to pursue a degree in Medicine.



After obtaining the required qualifications, he moved to Groningen in 2019, where he enrolled into the pre-master's program of Medicine at the Rijksuniversiteit of Groningen. Following the completion of his pre-master's year, his growing interest in research led to the opportunity to conduct research at the Department of Trauma Surgery in the University Medical Center Groningen during his master's program. This ultimately resulted in his acceptance into the MD/PhD program in 2021. As part of his study, he temporarily moved to Zwolle on two occasions for his clinical rotations, after which he successfully completed his master's degree in 2024.

During his PhD, Thijs primarily focused on patient-reported functional outcomes in patients with Tibial Plateau Fractures and as part of his research, he initiated and coordinated a prospective multicenter study. After completing his PhD program in 2025, he began working at the Department of Surgery in the Martini Hospital in Groningen. In the future, he hopes to fulfill his ambition of becoming a surgeon.

