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Decoding tibial plateau fracture classifications: a century of individualized insights in a systematic review

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- *Purpose:* We conducted a systematic review of all proposed classifications of tibial plateau fractures (TPFs) to facilitate comparison and identify the most effective reduction methods.
- *Methods:* PubMed, Scopus, Embase, Web of Science and Cochrane Library databases were searched for all the articles involving the suggestion of a new method of TPF classification. The descriptions of classifications, along with their suggested management strategies, were recorded.
- *Results:* Out of the 2,712 identified records, 69 were included in the study. Schatzker's and Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) classifications were the most frequently mentioned in the literature. The concept of a 'column' and posterior column fractures were introduced in 2010. Following this, posterior plateau fractures were further divided into posteromedial and posterolateral fractures. Proposed treatment approaches in most studies were based on the involved region and degree of displacement, while others considered fracture plane, deformity direction and type of fracture. The latest developments include the subclassification of the posterolateral column and consideration of associated injuries to the fibular head, eminentia, extensor mechanism and mechanical derangements along with the concept of the main deformity direction.
- *Conclusion:* The understanding of TPF patterns, associated injuries, surgical approaches and fixation methods has evolved in a compelling stepwise manner. Currently, there is no gold standard classification that addresses fracture configuration, soft-tissue injuries, principal direction of deformity, central eminence avulsions, extensor mechanism disruptions and mechanical derangements, while maintaining a simple and reliable categorization. Therefore, employing individualized classification systems remains the most logical approach at present. This study offers invaluable assistance in this regard.

Keywords: tibial plateau fracture; fracture classification; systematic review; fracture management

Introduction

Tibial plateau fractures (TPFs) account for nearly 1% of fractures in adult population (1). The annual incidence of TPF is estimated to be 10.3–13.3 in 100,000 (2, 3). The decision whether to perform a surgical fixation and

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choosing the appropriate approach for TPF depends on a number of factors, namely, the presence of associated neurovascular and moderate-to-severe soft-tissue damage, the anatomic and morphologic characteristics of the fracture, the degree of displacement and the presence of instability (4, 5). Mismanagement of TPF might result in joint stiffness and contractures, post-traumatic osteoarthritis, malunion, nonunion, malalignment and possible residual neurovascular injuries (6, 7, 8). Therefore, a classification that can take a higher number of aspects of fractures into consideration with acceptable reliability seems to provide a more accurate guidance for the surgeons. For this purpose, it is important for a trauma/knee surgeon to be familiar with practical classification systems in order to decide the best treatment plan.

Earlier classifications, such as Schatzker (9), classified TPF based on two-dimensional plain radiography, providing a poor view of plateau in the transverse plane. This led to mostly viewing plateau in the coronal plane. In addition, the accurate identification of the fracture plane is crucial as most of the commonly used surgical approaches recommend placement of the plate parallel to the fracture plane (10, 11). Therefore, to fill this gap, newer classifications such as the one proposed by Luo *et al.* in 2010 (12), and almost all of the classifications that were introduced afterward, used CT for a more detailed classification. They might bear a higher reliability compared to the classifications that are based on plain radiography (13, 14). With addition of other imaging modalities such as three-dimensional CT and MRI, more information can be obtained. Therefore, we attempted to systematically review all the classifications suggested for TPF so far, and the management strategies that were developed based on them.

Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines, and registered through International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42023479635.

Literature search and inclusion criteria

PubMed, Scopus, Embase, Web of science and Cochrane library databases were searched for articles proposing a new classification system for TPF by two reviewers (IMO and NR) for the following terms last updated in November 2023: ((‘tibial plateau’ OR ‘proximal tibia’ OR plateau) AND (Fracture* OR trauma) AND (classification* OR categor* OR taxonom*)) mentioned in article title, abstract or keywords. A new classification is defined as categorization of different patterns of TPF in a sample containing a number of patients in a way not similar to previous classifications. This could be an entirely new method of categorization, or alteration of the previously developed classifications (15).

Study selection

The EndNote version 20 (IBM, USA) software was used to import the extracted citations for reference list management and for the identification of duplicated references (16). The remaining references were screened based on the title and abstract. A senior reviewer (FV) was recalled in case of discrepancy between the two reviewers. The full-texts of the remaining articles were then retrieved and reviewed for existence of the inclusion criteria mentioned above for the final selection (17).

Definitions for data extraction

Data sheet contained the name of the first author, year of publication, number of patients in the study, male-to-female ratio, age, imaging modality used to develop the classification, number of classes and subclasses, the detailed description of the classification and the suggested surgical approach based on the classification (18).

Results

A total of 2,451 studies were identified through database searches. After removing duplicates, 1,739 studies remained. Subsequently, 1,320 studies were excluded following the screening of titles and abstracts. Of the 419 studies remaining, full-text screening identified 57 relevant studies for inclusion in this systematic review. In addition, 152 studies were identified through citation tracing, among which 12 were deemed relevant for inclusion (Fig. 1).

Classifications

A total of 69 classifications were recognized (Supplementary Table 1 (see section on Supplementary materials given at the end of the article)). Seventeen of these introduced subclassifications, modifications or revisions to the prior classifications. The most commonly mentioned classifications in the literature were the ones by Schatzker (9) and AO/OTA (19, 20).

Imaging techniques and described morphologies

Earlier classifications were described based on plain radiography and two-dimensional imaging. Brophy *et al.* (21) were the first to use MRI; Elstrom *et al.* (22) the first to use tomography; and Dias *et al.* (23), who modified Duparc and Ficat’s (24) X-ray based classification, were the first to

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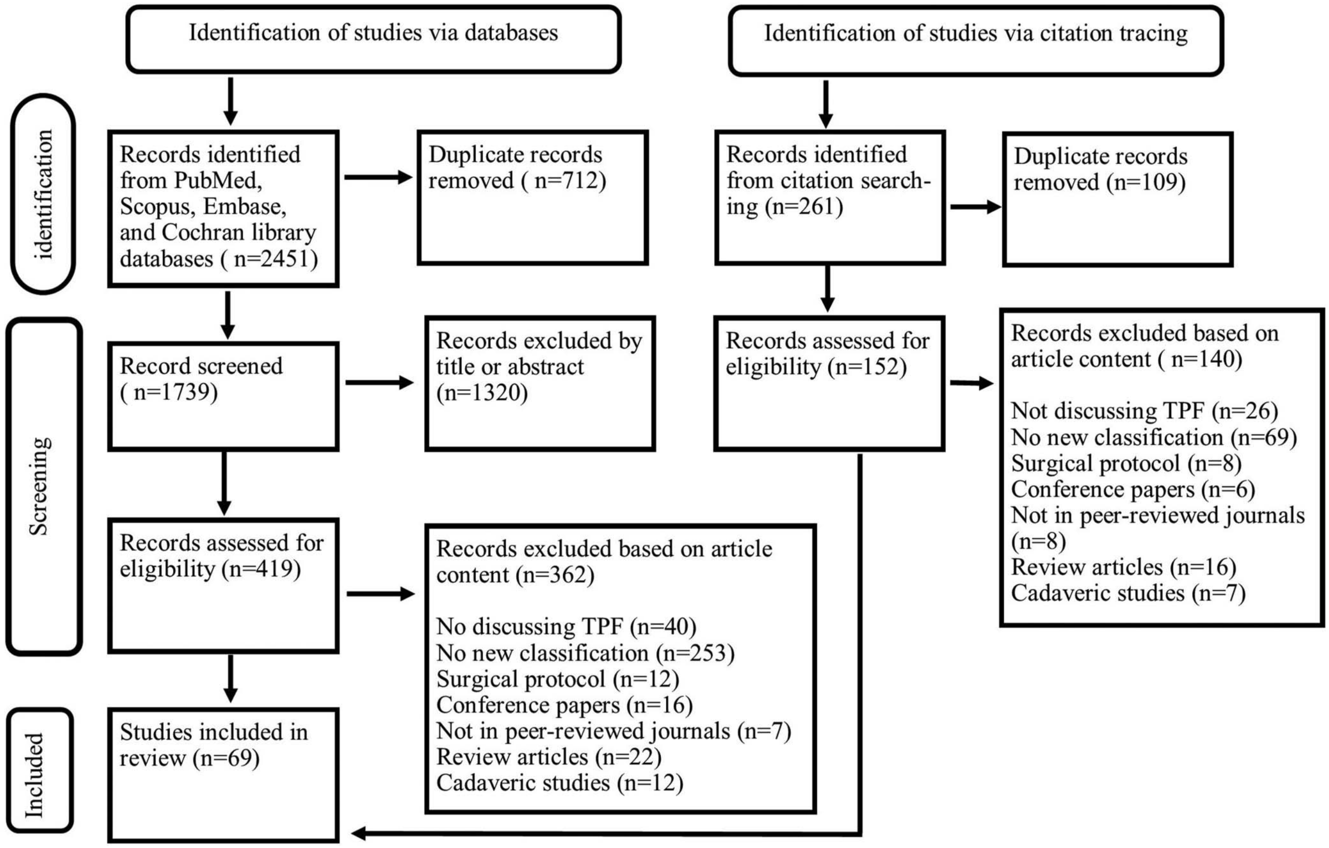

Figure 1

PRISMA flow diagram.

use CT. The most recent classifications insist on using three-dimensional CT as a complementory method.

Most of the classifications described so far are based on morphologic features of the fractures, namely split or wedge-shaped, depression and bicondylar types referred to as Y- or T-shaped fractures. The classification described by Moore (25), and its modifications by Hohl & Moore (26) and Brophy *et al.* (21), and the classifications by Khan *et al.* (27) and Yao *et al.* (28) included the rim avulsion fractures as well.

Luo *et al.* (12) were the first to suggest the concept of columns of medial, lateral and posterior based on CT. Chen *et al.* (29) divided the posterior column into posteromedial (PM) and posterolateral (PL) columns with different fracture morphologies (Table 1). Hoekstra *et al.* (30) isolated the part of posterior column between the anterior and posterior borders of the fibula, namely PL column, to modify the surgical approaches suggested by Luo *et al.* (12) for posterior column fractures. Zhang *et al.* (31) also suggested the subclassification of posterior TPF due to their different prognoses and surgical approaches.

The two most popular classifications by Schatzker (9) and AO/OTA (19, 20) were both revised in 2018, changing their imaging modality from plain radiography to CT scan. Therefore, the revision by Kfuri & Schatzker in 2018 (32) added posterior and anterior divisions, resulting in four quadrants. They also introduced the concept of ‘main fracture plane’ based on the exit points of the wedge fragment from the articular and metaphyseal cortex to help with the acknowledgment of most optimal direction of plate and screw placement. Other authors tried to further classify the Schatzker’s (9) classification, mostly by categorizing different morphologies of medial plateau fractures. Wahlquist *et al.* (33) divided medial TPF based on the location of fracture lines relative to intercondylar spines, and stated that the importance of doing so lies in their different prognoses and severities. Krause *et al.* (34), Gebel *et al.* (35), Chang *et al.* (36), Saragaglia *et al.* (37) and Yao *et al.* (28) incorporated the bare-area or the non-weight bearing area of the plateau, unlike the other ones.

Mechanism-based classifications

Hayes *et al.* (38), the first to describe a mechanism-based classification in 2000, included ten types of injury mechanism including two entities of patellar dislocation

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Table 1 Practical guide to individualized use of TPF classifications.

Specific feature	References, *n*	Study	Year*
Rim avulsion	5	Moore (25)	**1981**
		Hohl & Moore (26)	1990
		Brophy *et al.* (54)	1996
		Khan *et al.* (27)	2000
		Yao *et al.* (28)	2018
Tibial tuberosity	5	Duparc & Cavagna (78)	**1987**
		Ruggieri *et al.* (45)	1991
		Chang *et al.* (36)	2018
		Yao *et al.* (28)	2018
		Wang *et al.* (46)	2020
Mechanism	6	Hayes *et al.* (38)	**2000**
		Hua *et al.* (39)	2019
		Zhang *et al.* (41)	2019
		Xie *et al.* (40)	2020
		Wang *et al.* (43)	2021
		Hu *et al.* (42)	2022
Fibula and subtype of fibula	1	Yao *et al.* (28)	**2018**
Proximal tibiofibular joint instability	1	Yao *et al.* (28)	**2018**
Posterolateral as a separate column	21	Chang *et al.* (79)	**2012**
		Chang *et al.* (80)	2014
		Sun *et al.* (81)	2015
		Chen *et al.* (29)	2015
		Krause *et al.* (50)	2016
		Hoekstra *et al.* (30)	2017
		Martinez-Rondanelli *et al.* (82)	2017
		Meinberg *et al.* (83)	2018
		Gebel *et al.* (35)	2018
		Kfuri & Schatzker (32)	2018
		Yao *et al.* (28)	2018
		Anwar *et al.* (84)	2019
		Hua *et al.* (39)	2019
		Zhang *et al.* (41)	2019
		Bernholt *et al.* (85)	2020
		Saragaglia *et al.* (37)	2021
		Sim *et al.* (68)	2021
		Wu *et al.* (48)	2021
		Zhang *et al.* (86)	2021
		Zhu *et al.* (62)	2022
		Zhu *et al.* (53)	2023
Subtype for posterolateral column fracture	7	Chen *et al.* (29)	**2015**
		Krause *et al.* (50)	2016
		Krause *et al.* (34)	2016
		Menzdorf *et al.* (49)	2020
		Saragaglia *et al.* (37)	2021
		Sim *et al.* (68)	2021
		Zhu *et al.* (53)	2023
Cartilage degeneration	1	Zhang *et al.* (31)	**2018**
MRI-based	5	Brophy *et al.* (54)	**1996**
		Hayes *et al.* (38)	2000
		Bernholt *et al.* (85)	2020
		Menzdorf *et al.* (49)	2020
		Tunçez *et al.* (47)	2022
Tibial spine	4	Chang *et al.* (36)	**2018**
		Gebel *et al.* (35)	2018
		Yao *et al.* (28)	2018
		Wang *et al.* (46)	2020
MCL injury	1	Yao *et al.* (28)	**2018**
LCL/ACL/PCL/PLC tear	2	Yao *et al.* (28)	**2018**
		Tunçez *et al.* (47)	2022
MDD	1	Boluda-Mengod *et al.* (65)	**2021**
Meniscus	1	Tunçez *et al.* (47)	**2022**
Posterocentral as a separate area	6	Krause *et al.* (50)	**2016**
		Krause *et al.* (34)	2016
		Meinberg *et al.* (83)	2018
		Boluda-Mengod *et al.* (65)	2021
		Saragaglia *et al.* (37)	2021
		Zhu *et al.* (62)	2022
Extensor mechanism injury (quadriceps and patellar tendon, patella)	2	Hayes *et al.* (38)	**2000**
		Wang *et al.* (46)	2020
Considered skin/ subcutaneous (soft tissue) injury	0	NONE	

(Continued)

*First year is presented in bold.
MDD, main deformity direction; LCL, lateral collateral ligament; PLC, posterolateral corner; ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MCL, medial collateral ligament; TPF, tibial plateau fracture.

and direct trauma that are only described in their classification. Hua *et al.* (39) and Xie *et al.* (40) included six types based on injury mechanism. Zhang *et al.* (41) included nine types mainly based on posterior tibial slope angle (PTSA) and tibial plateau angle, with inclusion of axial-loading forces causing bicondylar fractures, in addition to the types described by Xie *et al.* (40) and Hua *et al.* (39). Hu *et al.* (42) divided flexion-type TPF into five subtypes and rotary forces. Wang *et al.* (43) analyzed the injury mechanisms causing each type of medial TPF described by Wahlquist *et al.* (44). Hua *et al.* (39) divided Schatzker (9) type IV fractures based on their main mechanism, which is varus, subcategorized into flexion, extension and hyperextension forces.

Soft-tissue extensions of classifications

Most of the classifications did not include associated soft-tissue injuries. Brophy *et al.* (21), Moore (25), Yao *et al.* (28) and Duparc and Ficat (24) described avulsion fractures of ligamentous insertion sites. Ruggieri *et al.* (45) mentioned collateral ligament injuries; Wang *et al.* (46) included the

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avulsion of posterior cruciate ligament (PCL), anterior cruciate ligament (ACL) and tibial tuberosity as the insertion site of patellar tendon. Tuncez *et al.* (47) modified Schatzker's (9) classification by the addition of letters to the main fracture types for demonstration of associated ligamentous/meniscus injury; and Yao *et al.* (28) added two extensions of ligamentous tear or avulsion of their insertion site to a number of the subtypes. Yao *et al.* (28) described the most precise subclassifications regarding ligamentous disruptions. Yao *et al.* (28) and Wu *et al.* (48) included fibular fracture morphologies as well. The most comprehensive classification so far is the one by Yao *et al.* (28), with 28 separate entities including fracture and associated injury descriptions.

Treatment approaches based on classifications

A total of 34 studies were found to introduce a classification and a treatment approach based on the classification simultaneously. Fifteen of these studies also reported the patient outcomes based on their suggested managements with different tools, radiographic or clinical.

The earliest studies suggested conservative management. Soft-tissue and ligamentous injuries were not acknowledged very well and were usually dealt with immobilization. Moore *et al.* (25), who described fracture-dislocations, emphasized on the importance of ligamentous injuries, and highlighted the need for a surgical approach according to the involved ligaments. Brophy *et al.* (21) considered intra-articular soft-tissue injuries as an indication for operative treatment based on MR studies. However, in the absence of MRI, ligamentous injuries were diagnosed by stress examination in other studies. In the next step of evolution, nonoperative managements were only advised for fractures with minimal displacement and instability. Different indications for surgery have been described ever since: articular displacements >2 mm (39, 49, 50), 3 mm (51, 52, 53) and 5 mm (54, 55), or widening >5 mm (39, 56), 4 mm (26, 57) and 5–10 mm (56), and varus or valgus deformity >10° in full extension (58). However, application of rafting screws and plates to provide extra support only became popular in the more recent literature.

Luo *et al.* (12) were one of the first to consider the surgical management of TPFs based on their locations on the articular surface, described as columns, and suggested different approaches and incisions for involvement of each column.

The reported incidence of posterior TPF ranges from 28.8 to 61.9% (59, 60, 61). Recognizing posterior column fractures, Luo *et al.* (12) recommended a PM approach using an inverted L-incision for these fractures. Subsequent classifications have consistently divided the posterior column into PM and PL parts, a division deemed necessary due to the challenging access to PL areas of the tibial plateau.

Hoekstra *et al.* (30) recommended a single lateral approach for lateral column fractures extending into the posterolateral column (PLC). In contrast, Luo *et al.* (12) categorized this type of fracture as a 'two-column' fracture, involving both the lateral and posterior columns, and suggested using anterior and inverted L-shaped posteromedial (PM) incisions. Several authors following Luo *et al.* (12) also recommended fixing PLC fractures through a PM approach. Reduction of PL fractures through a PM approach can be difficult and often insufficient, with a risk of screw misplacement due to interference from the gastrocnemius and popliteus muscles, which obstruct the surgeon's view (62). Chen *et al.* (29) recommended an inverse L-shaped incision in a PL direction for these fractures. However, fixing isolated PLC fractures through a PL approach also presents challenges because of the proximity of the fibular head and key soft-tissue structures behind the knee, such as the peroneal nerve, popliteal artery and popliteus tendon (63). Chang *et al.* (36) suggested the use of direct PL approach without osteotomy (64) or with osteotomies of the fibular neck or lateral femoral epicondyle for fixing isolated PL column fractures. They also recommended an inverted L-shaped incision for simultaneous PM and PL fractures, similar to other authors. However, Boluda *et al.* (65) suggested modified Lobenhoffer's approach (66) for simultaneous access to the PL and PM columns instead of the inverse L-shaped incision. For isolated PL column fractures, they used either the direct PL approach proposed by Yu *et al.* (64) or an extended AL approach. In the extended AL approach, the incision can be lengthened to access the PL column, allowing direct PL buttress plating through the PL window, as described by Frosch *et al.* (67). This technique minimizes soft-tissue injury and preserves the anterior tibial artery, avoiding the need for fibular head osteotomy (Fig. 2).

Zhu *et al.* (53) suggested that isolated depression fractures of the PL column without cortical involvement can be fixed through the lateral window. If the cortex is involved (uncontained defect), simultaneous use of PL and lateral windows is necessary to provide direct buttress. Kfuri & Schatzker (32) compared the direct lateral and PM approaches for PLC fractures based on their 'main fracture plane' concept, which advocates using a buttress plate parallel to the plane in split fractures. They noted that the direct posterolateral approach provides limited distal access and allows only short plates due to neurovascular structures, whereas the extended PM approach supports longer plates, although with limited visibility. Sim *et al.* (68) argued that different regions of the PLC should be approached based on their subtypes. They recommended an extended AL incision for the anterior regions of PLC and a PM incision for the medial regions of PLC. For PLC areas obstructed by the fibula, a fibular head osteotomy was still advised.

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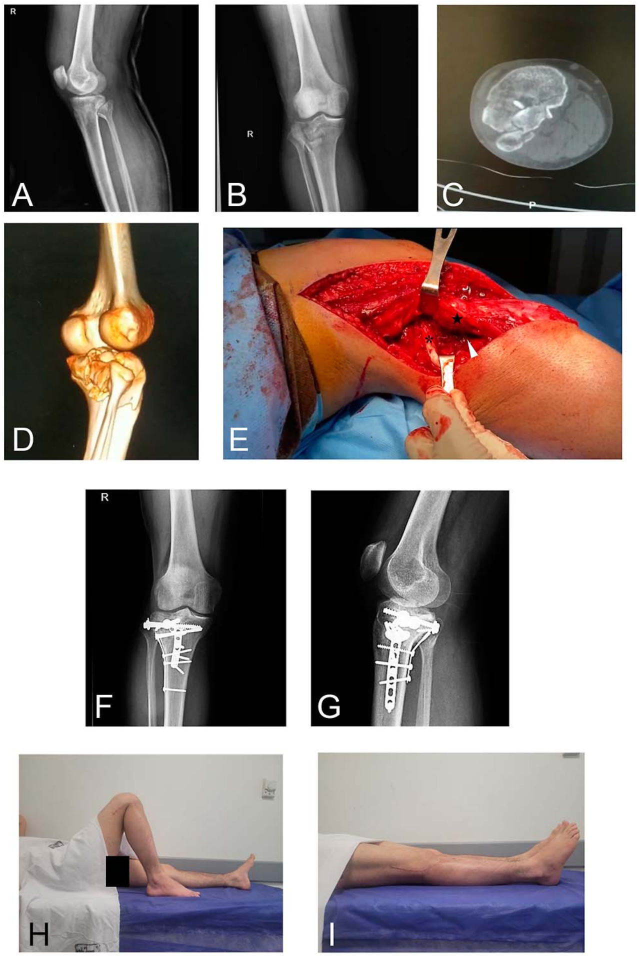

Figure 2

Example of a posterolateral + anterolateral right TPF in a 28-year-old male, who underwent surgery through an extended anterolateral approach. (A, B, C, D) Preoperative radiograph and CT images. (E) Intraoperative view of posterolateral window, star: common peroneal nerve and biceps tendon (retracted anteriorly), arrowhead: direct posterolateral (frosh) interval, asterisk: lateral head of the gastrocnemius and soleus muscles (retracted posteriorly). (F and G) Postoperative radiographs after 6 months follow-up. (H and I) Final knee range of motion after 6 months from surgery.

In addition, Luo *et al.*'s (12) three-column classification defines compression fractures as 'zero-column' fractures but does not specifically address their management. This may be due to the ability of surgeons to reduce compression fractures through metaphyseal windows using various approaches that are not necessarily column-specific. Similarly, in the updated three-column concept by Wang *et al.* (61), minimally invasive techniques and metaphyseal windows are recommended for reducing compression fractures. However, an open surgical approach with a subchondral rafting screw is advised for rim compression fractures to prevent instability (32). Therefore, a column-specific surgical approach appears essential for articular rim compression fractures (non-contained depression).

Dhillon *et al.* (69) used the concept of compression and tension sides to determine the surgical approach. Boluda *et al.* (65) were one of the first to consider all the possible combinations of regional involvements (including four-column TPF) and suggested special surgical approaches according to the concept of 'main deformity direction' (MDD) (65, 70).

Discussion

The findings of this study demonstrate that the challenge of classifying TPF not only remains unresolved but has also become increasingly complex, reaching a peak in the recent decade. The number of TPF classification systems proposed over the past decade is comparable to those introduced in the preceding 50 years. This reflects a significant evolution in our understanding of TPFs, their treatment and associated injuries (Fig. 3).

Historically, management of TPF has undergone a remarkable stepwise progression (Fig. 4). This began with a shift from nonoperative management to more advanced operative interventions. Imaging techniques have also evolved from the use of simple plain radiographs to more sophisticated modalities such as CT scans and MRI, allowing for a more detailed understanding of fracture characteristics. Initially, TPF was analyzed predominantly in the coronal plane, but the approach has expanded to treat these fractures as three-dimensional entities, considering the axial, sagittal and coronal planes. In addition, the recognition of the posterolateral and posteromedial columns as distinct anatomical regions was a key development.

These represent the primary and intermediate phases of our evolving understanding of TPF. More recent developments introduced an even more nuanced view. Emphasis is now placed on the mechanism of injury, and on the significance of soft-tissue damage and associated injuries, factors that were often overlooked in earlier

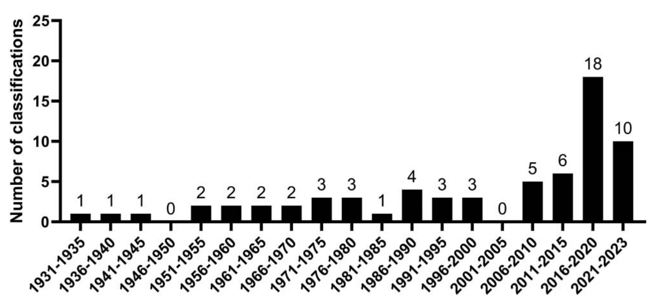

Figure 3

Historical bar chart demonstrating the number of TPF classifications proposed in the past century.

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Figure 4

Suggested diagram for stepwise evolution of TPF journey.

classifications. The incorporation of the concept of MDD into treatment protocols marks another critical advancement, allowing for more tailored and comprehensive management strategies for TPF (65).

Fibular head fractures are frequently associated with medial condylar TPF and can result from avulsion or the 'push–pull' mechanism (arcuate sign) (39). Few classifications have considered simultaneous tibial plateau and fibular head fractures. Yao *et al.* (28) included the fibula as a distinct segment in their classification, with additional extensions to describe injuries to the lateral collateral ligament (LCL) or avulsion of its insertion at the lateral femoral epicondyle. They characterized the hyperextension complex TPF as involving compression of the bare area, alteration or reversal of the PTSA, tension fractures of the posterior cortex, fibular head avulsion fractures or disruption of the PCL or posterolateral corner (PLC). Furthermore, fibular head fractures can lead to valgus instability in cases of lateral plateau fractures, while an intact fibular head in bicondylar fractures may cause varus deformity (71, 72).

The role of soft-tissue injuries in TPF prognosis is discussed in several studies. Schatzker (9) noted that type IV medial condylar fractures have the worst prognosis, likely due to the associated soft-tissue damage. Wahlquist *et al.* (44) observed worsening outcomes in medial condylar fractures as the fracture line extends laterally toward the intercondylar spines, with an increased risk of soft-tissue complications, including neurovascular injuries and compartment syndrome. Brophy *et al.* (21) emphasized the importance of MRI for detecting meniscal entrapment in the fracture line, which may lead to failed closed reductions, although this technique is less commonly used today. Wu *et al.* (48), similar to Yao *et al.* (28), is among the few studies to highlight avulsion fractures of the intercondylar eminence and associated ACL and PCL avulsion.

TPFs were historically referred to as 'fender' or 'bump' fractures, primarily involving lateral condylar fractures caused by car accidents. However, earlier studies introduced other mechanisms, including falls or vehicular accidents involving varus, valgus and axial forces. Recent mechanism-based classifications (38, 39, 40, 41, 73) have identified hyperextension and flexion injuries leading to anterior and posterior compression of the tibial plateau, respectively. These classifications aid in predicting concomitant soft-tissue injuries on the tension side and the force direction required for reduction (41, 74, 75). For instance, detecting hyperextension injuries alerts surgeons to potential soft-tissue injuries in the PLC, along with the risk of future fracture collapse causing recurvatum deformity and instability. Recent studies have shown a relatively high rate of PLC injuries in hyperextension varus TPFs, especially in cases without fracture of the posterior column cortex with a small anteromedial fracture area. (76).

Although all of the published TPF classifications were included in this study, the reliability of the classifications was not reported or compared. This information is detailed in a separate study (77). It seems that in the most comprehensive classification systems, reduced reliability is inevitable. Therefore, a gold standard classification with high reliability along with comprehensive consideration of all TPF features does not exist, and individualized use based on the patients TPF configuration and associated injuries is the logical approach (Table 1). The authors' preferred algorithm for deciding the surgical approach based on fracture configuration is provided in Fig. 5.

Conclusion

The understanding of plateau fracture patterns, associated injuries, surgical approaches and fixation methods has evolved in a compelling stepwise manner. Currently, no gold standard classification addresses fracture configuration, soft-tissue injuries, principal direction of deformity, central eminence avulsions, extensor mechanism disruptions and mechanical derangements, all while maintaining a simple and reliable categorization. Therefore, employing individualized classification systems remains the most logical approach at present. This study offers invaluable assistance in this regard.

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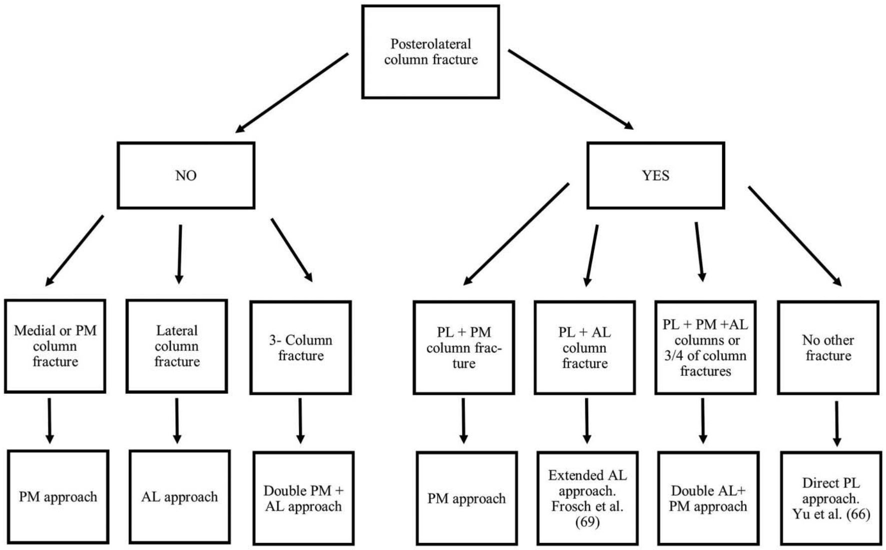

Figure 5
Authors' preferred algorithm for deciding surgical approach in TPF treatment.

Supplementary materials

This is linked to the online version of the paper at https://doi.org/10.1530/EOR-2024-0184.

ICMJE Statement of Interest

The authors declare that they have no conflicts of interest that are relevant to the content of this work.

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Author contribution statement

F Vosoughi helped in conceptualization, validation, writing of the review, editing and supervision. I M Oskouie helped with methodology, conceptualization and writing of the original draft. N Rahimdoost helped in conceptualization, investigation and writing of the original draft. R Pesantez helped with editing the manuscript and preparation of the final draft.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

The authors all agree for the submission and publication of the manuscript.

References

1 Moore TM, Patzakis MJ & Harvey JP. Tibial plateau fractures: definition, demographics, treatment rationale, and long-term results of closed traction management or operative reduction. *J Orthop Trauma* 1987 **1** 97–119. (https://doi.org/10.1097/00005131-198702010-00001)

2 Elsoe R, Larsen P, Nielsen NP, *et al.* Population-based epidemiology of tibial plateau fractures. *Orthopedics* 2015 **38** e780–e786. (https://doi.org/10.3928/01477447-20150902-55)

3 Court-Brown CM & Caesar B. Epidemiology of adult fractures: a review. *Injury* 2006 **37** 691–697. (https://doi.org/10.1016/j.injury.2006.04.130)

4 Schatzker J & Kfuri M. Revisiting the management of tibial plateau fractures. *Injury* 2022 **53** 2207–2218. (https://doi.org/10.1016/j.injury.2022.04.006)

5 Mthethwa J & Chikate A. A review of the management of tibial plateau fractures. *Musculoskelet Surg* 2018 **102** 119–127. (https://doi.org/10.1007/s12306-017-0514-8)

6 Chen P, Shen H, Wang W, *et al.* The morphological features of different Schatzker types of tibial plateau fractures: a three-dimensional computed tomography study. *J Orthop Surg Res* 2016 **11** 94. (https://doi.org/10.1186/s13018-016-0427-5)

7 Pulfrey S & Lahiffe B. Two fractures of the lower extremity not to miss in the emergency department. *Can Fam Physician* 2013 **59** 1069–1072.

8 Rudran B, Little C, Wiik A, *et al.* Tibial Plateau fracture: anatomy, diagnosis and management. *Br J Hosp Med* 2020 **81** 1–9. (https://doi.org/10.12968/hmed.2020.0339)

9 Schatzker J, McBroom R & Bruce D. The tibial plateau fracture. The Toronto experience 1968–1975. *Clin Orthop Relat Res* 1979 **138** 94–104.

10 McGonagle L, Cordier T, Link BC, *et al.* Tibia plateau fracture mapping and its influence on fracture fixation. *J Orthop Traumatol* 2019 **20** 12. (https://doi.org/10.1186/s10195-019-0519-1)

11 Weaver MJ, Harris MB, Strom AC, *et al.* Fracture pattern and fixation type related to loss of reduction in bicondylar tibial plateau fractures. *Injury* 2012 **43** 864–869. (https://doi.org/10.1016/j.injury.2011.10.035)

12 Luo CF, Sun H, Zhang B, *et al.* Three-column fixation for complex tibial plateau fractures. *J Orthop Trauma* 2010 **24** 683–692. (https://doi.org/10.1097/bot.0b013e3181d436f3)

13 Audigé L, Bhandari M & Kellam J. How reliable are reliability studies of fracture classifications? A systematic review of their methodologies. *Acta Orthop Scand* 2004 **75** 184–194. (https://doi.org/10.1080/00016470412331294445)

14 Vosoughi F, Oskouie IM, Rahimdoost N, *et al.* Intrarater and inter-rater reliability of tibial plateau fracture classifications: systematic review and meta-analysis. *JBJS Open Access* 2024 **9** e23. (https://doi.org/10.2106/jbjs.oa.23.00181)

15 Mohammadi A, Inanloo SH, Rezaeian A, *et al*. Hypo-albuminemia and perioperative renal transplant-related infections: a systematic review and meta-analysis. *Urol J* 2024 **21** 7943. (https://doi.org/10.22037/uj.v21i.7943)

16 Hupe M. EndNote X9. *J Electron Resour Med Libr* 2019 **16** 117–119. (https://doi.org/10.1080/15424065.2019.1691963)

17 Valizadeh A, Moassefi M, Nakhostin-Ansari A, *et al.* Automated diagnosis of autism with artificial intelligence: state of the art. *Rev Neurosci* 2024 **35** 141–163. (https://doi.org/10.1515/revneuro-2023-0050)

18 Valizadeh A, Moassefi M, Nakhostin-Ansari A, *et al.* Accuracy of machine learning algorithms for the diagnosis of autism spectrum disorder based on cerebral sMRI, rs-fMRI, and EEG: protocols for three systematic reviews and meta-analyses. *medRxiv* 2021. (https://doi.org/10.1101/2021.06.29.21254249)

19 Marsh J, Slongo TF, Agel J, *et al.* Fracture and dislocation classification compendium-2007: orthopaedic trauma association classification, database and outcomes committee. *J Orthop Trauma* 2007 **21** (Supplement 10) S1–S6. (https://doi.org/10.1097/00005131-200711101-00001)

20 Fracture and dislocation compendium. Orthopaedic trauma association committee for coding and classification. *J Orthop Trauma* 1996 **10** (Supp. 1) 1–154.

21 Brophy DP, O'Malley M, Lui D, *et al.* MR imaging of tibial plateau fractures. *Clin Radiol* 1996 **51** 873–878. (https://doi.org/10.1016/s0009-9260(96)80086-9)

22 Elstrom J, Pankovich AM, Sassoon H, *et al.* The use of tomography in the assessment of fractures of the tibial plateau. *J Bone Joint Surg Am* 1976 **58** 551–555. (https://doi.org/10.2106/00004623-197658040-00021)

23 Dias JJ, Stirling AJ, Finlay DB, *et al.* Computerised axial tomography for tibial plateau fractures. *J Bone Joint Surg Br* 1987 **69-B** 84–88. (https://doi.org/10.1302/0301-620x.69b1.3818741)

24 Duparc J & Ficat P. Fractures articulaires de l'extrémité supérieure du tibia. *Rev Chir Orthop Reparatrice Appar Mot* 1960 **46** 399–486.

25 Moore TM. Fracture--dislocation of the knee. *Clin Orthop Relat Res* 1981 **156** 128–140. (https://doi.org/10.1097/00003086-198105000-00015)

26 Hohl M & Moore TM. Articular fractures of proximal tibia. In *Surgery of the Musculoskeletal System*, vol 4, 2nd edn, pp 3471–3497. Ed CM Evarts. New York: Churchill Livingstone, 1990.

27 Khan RMS, Khan SH, Ahmad AJ, *et al.* Tibial plateau fractures: a new classification scheme. *Clin Orthop Relat Res* 2000 **375** 231–242. (https://doi.org/10.1097/00003086-200006000-00028)

28 Yao X, Xu Y, Yuan J, *et al.* Classification of tibia plateau fracture according to the "four-column and nine-segment. *Injury* 2018 **49** 2275–2283. (https://doi.org/10.1016/j.injury.2018.09.031)

29 Chen HW, Chen CQ & Yi XH. Posterior tibial plateau fracture: a new treatment-oriented classification and surgical management. *Int J Clin Exp Med* 2015 **8** 472–479.

30 Hoekstra H, Kempenaers K & Nijs S. A revised 3-column classification approach for the surgical planning of extended lateral tibial plateau fractures. *Eur J Trauma Emerg Surg* 2017 **43** 637–643. (https://doi.org/10.1007/s00068-016-0696-z)

31 Zhang Y, Song L, Li X, *et al.* Flexion-valgus unicondylar tibial plateau depression fracture pattern: classification and treatment. *Injury* 2018 **49** 852–859. (https://doi.org/10.1016/j.injury.2018.03.009)

32 Kfuri M & Schatzker J. Revisiting the Schatzker classification of tibial plateau fractures. *Injury* 2018 **49** 2252–2263. (https://doi.org/10.1016/j.injury.2018.11.010)

33 Wahlquist M, Iaguilli N, Ebraheim N, *et al.* Medial tibial plateau fractures: a new classification system. *J Trauma* 2007 **63** 1418–1421. (https://doi.org/10.1097/ta.0b013e3181469df5)

34 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. (https://doi.org/10.1016/j.injury.2016.09.014)

35 Gebel PJ, Tryzna M, Beck T, *et al.* Tibial plateau fractures: fracture patterns and computed tomography evaluation of tibial plateau fractures in winter sports. *Orthop Rev* 2018 **10** 7517. (https://doi.org/10.4081/or.2018.7517)

36 Chang SM, Hu SJ, Du SC, *et al.* Four-quadrant/column classification of tibial plateau fractures. *Int Orthop* 2018 **42** 725–727. (https://doi.org/10.1007/s00264-017-3733-6)

37 Saragaglia D, Giunta JC, Gaillot J, *et al.* Are Schatzker and AO classifications accurate enough to classify tibial plateau fractures in alpine skiers? *Int Orthop* 2021 **45** 1863–1869. (https://doi.org/10.1007/s00264-021-04993-8)

38 Hayes CW, Brigido MK, Jamadar DA, *et al.* Mechanism-based pattern approach to classification of complex injuries of the knee depicted at MR imaging. *Radiographics* 2000 **20** S121–S134. (https://doi.org/10.1148/radiographics.20.suppl_1.g00oc21s121)

39 Hua K, Jiang X, Zha Y, *et al.* Retrospective analysis of 514 cases of tibial plateau fractures based on morphology and injury mechanism. *J Orthop Surg Res* 2019 **14** 267. (https://doi.org/10.1186/s13018-019-1321-8)

40 Xie X, Zhan Y, Wang Y, *et al.* Comparative analysis of mechanism-associated 3-dimensional tibial plateau fracture patterns. *J Bone Joint Surg Am* 2020 **102** 410–418. (https://doi.org/10.2106/jbjs.19.00485)

41 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. (https://doi.org/10.1302/2046-3758.88.bjr-2018-0331.r1)

42 Hu Y, Peng A, Wang S, *et al.* Flexion tibial plateau fractures: 3-dimensional CT simulation-based subclassification by injury pattern. *Orthop Surg* 2022 **14** 543–554. (https://doi.org/10.1111/os.13190)

43 Wang S, Peng AQ, Pan S, *et al.* Analysis of medial tibial plateau fracture injury patterns using quantitative 3D measurements. *J Orthop Sci* 2021 **26** 831–843. (https://doi.org/10.1016/j.jos.2020.08.008)

44 Wahlquist M, Iaguilli N, Ebraheim N, *et al.* Medial tibial plateau fractures: a new classification system. *J Trauma* 2007 **63** 1418–1421. (https://doi.org/10.1097/ta.0b013e3181469df5)

45 Ruggieri P, Biagini R, Ruggieri N, *et al.* Complex fractures of the tibial plateau. *Chir Organi Mov* 1991 **76** 209–215.

46 Wang QM, Yu JW, Zhong ZY, *et al.* Subdivision of injured area for Schatzker IV tibial plateau fracture repair: a report of 12 cases. *J Orthop Sci* 2020 **25** 481–486. (https://doi.org/10.1016/j.jos.2019.05.020)

47 Tunçez M, Akan I, Seyfettinoglu F, *et al.* Is it necessary to add soft tissue injury to the classification in tibial plateau fracture management? *Cureus* 2022 **14** e22236. (https://doi.org/10.7759/cureus.22236)

48 Wu LP, Mayr HO, Cai Q, *et al.* A new three-dimensional classification of proximal tibiofibular fractures: a multicenter study. *Orthop Surg* 2021 **13** 2442–2456. (https://doi.org/10.1111/os.13161)

49 Menzdorf L, Drenck T, Akoto R, *et al.* Clinical results after surgical treatment of posterolateral tibial plateau fractures ("apple bite fracture") in combination with ACL injuries. *Eur J Trauma Emerg Surg* 2020 **46** 1239–1248. (https://doi.org/10.1007/s00068-020-01509-8)

50 Krause M, Preiss A, Meenen NM, *et al.* Fracturoscopy is superior to fluoroscopy in the articular reconstruction of complex tibial plateau fractures-an arthroscopy assisted fracture reduction technique. *J Orthop Trauma* 2016 **30** 437–444. (https://doi.org/10.1097/bot.0000000000000569)

51 Hohl M & Luck JV. Fractures of the tibial condyle: a clinical and experimental study. *J Bone Joint Surg Am* 1956 **38** 1001–1018. (https://doi.org/10.2106/00004623-195638050-00005)

52 Hohl M. Tibial condylar fractures. *J Bone Joint Surg Am* 1967 **49** 1455–1467. (https://doi.org/10.2106/00004623-196749070-00022)

53 Zhu B, Chen J, Zhang Y, *et al.* Revisiting the flexion-valgus type unicondylar posterolateral tibial plateau depression fracture pattern: classification and treatment. *J Orthop Surg Res* 2023 **18** 825. (https://doi.org/10.1186/s13018-023-04318-y)

54 Brophy D, O'malley M, Lui D, *et al.* MR imaging of tibial plateau fractures. *Clin Radiol* 1996 **51** 873–878. (https://doi.org/10.1016/s0009-9260(96)80086-9)

55 Palmer I. Fractures of the upper end of the tibia. *J Bone Joint Surg Br* 1951 **33-B** 160–166. (https://doi.org/10.1302/0301-620x.33b2.160)

56 Schulak DJ & Gunn DR. Fractures of tibial plateaus. A review of the literature. *Clin Orthop Relat Res* 1975 166–177. (https://doi.org/10.1097/00003086-197506000-00025)

57 Hohl M. Managing the challenge of tibial plateau fractures. *J Musculoskel Med* 1991 **8** 70–86.

58 Rasmussen PS. Tibial condylar fractures: impairment of knee joint stability as an indication for surgical treatment. *J Bone Joint Surg Am* 1973 **55** 1331–1350. (https://doi.org/10.2106/00004623-197355070-00001)

59 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. (https://doi.org/10.1007/s00264-017-3566-3)

60 Molenaars RJ, Mellema JJ, Doornberg JN, *et al.* Tibial Plateau fracture characteristics: computed tomography mapping of lateral, medial, and bicondylar fractures. *J Bone Joint Surg Am* 2015 **97** 1512–1520. (https://doi.org/10.2106/jbjs.n.00866)

61 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. (https://doi.org/10.1016/j.injury.2016.04.026)

62 Zhu F, Jiao J, Huang Y, *et al.* A preliminary study of the surgical approach for posterior tibial plateau fractures: based on posterior fragment segment classification. *Injury* 2022 **53** 3820–3827. (https://doi.org/10.1016/j.injury.2022.09.009)

63 Hoekstra H, Rosseels W, Luo CF, *et al.* A combined posterior reversed L-shaped and anterolateral approach for two column tibial plateau fractures in Caucasians: a technical note. *Injury* 2015 **46** 2516–2519. (https://doi.org/10.1016/j.injury.2015.10.014)

64 Yu GR, Xia J, Zhou JQ, *et al.* Low-energy fracture of posterolateral tibial plateau: treatment by a posterolateral prone approach. *J Trauma Acute Care Surg* 2012 **72** 1416–1423. (https://doi.org/10.1097/ta.0b013e318248e7e5)

65 Boluda-Mengod J, Guimerà-García V, Olías-López B, *et al.* A proposal of a new algorithm for decision-making approaches in open reduction and internal fixation of complex tibial plateau fractures – SOTA algorithm (Spanish Orthopaedic Trauma Association). *Injury* 2021 **52** (Supplement 4) S87–s98. (https://doi.org/10.1016/j.injury.2021.03.064)

66 Lobenhoffer P, Gerich T, Bertram T, *et al.* Particular posteromedial and posterolateral approaches for the treatment of tibial head fractures. *Unfallchirurg* 1997 **100** 957–967. (https://doi.org/10.1007/s001130050218)

67 Frosch KH, Balcarek P, Walde T, *et al.* A new posterolateral approach without fibula osteotomy for the treatment of tibial plateau fractures. *J Orthop Trauma* 2010 **24** 515–520. (https://doi.org/10.1097/bot.0b013e3181e5e17d)

68 Sim JA, Park JH, Na YG, *et al.* Three-column subdivision for isolated posterolateral tibial plateau fractures and perspective surgical approaches. *Knee* 2021 **33** 93–101. (https://doi.org/10.1016/j.knee.2021.08.033)

69 Dhillon MS, Patel S & K P. Simple four column classification can dictate treatment for intra articular tibial plateau fractures much better than ten segment classification. *Injury* 2017 **48** 1276–1278. (https://doi.org/10.1016/j.injury.2017.03.031)

70 Vaziri AS, Moradkhani G, Karimpour M, *et al.* Management of tibial nonunion and osteoarthritis using a 3D-printed titanium cone: a case report. *Trauma Case Rep* 2023 **48** 100937. (https://doi.org/10.1016/j.tcr.2023.100937)

71 Sarmiento A, Kinman PB, Latta LL, *et al.* Fracutres of the proximal tibia and tibial condyles: a clinical and laboratory comparative study. *Clin Orthop Relat Res* 1979 **145** 136–145. (https://doi.org/10.1097/00003086-197911000-00017)

72 Tahami M, Vaziri AS, Tahmasebi MN, *et al.* Practical approach to the native distal femur fractures in the elderly: a rapid review over the recent trends. *Injury* 2022 **53** 2389–2394. (https://doi.org/10.1016/j.injury.2022.05.014)

73 Wang S, Peng AQ, Pan S, *et al.* Analysis of medial tibial plateau fracture injury patterns using quantitative 3D measurements. *J Orthop Sci* 2021 **26** 831–843. (https://doi.org/10.1016/j.jos.2020.08.008)

74 Carlson DA. Posterior bicondylar tibial plateau fractures. *J Orthop Trauma* 2005 **19** 73–78. (https://doi.org/10.1097/00005131-200502000-00001)

75 Sharafatvaziri A, Shayan-Moghadam R, Tahmaseb MN, *et al*. Comminuted patellar fracture: a summary of the latest updates. *J Orthop Spine Trauma* 2019 **5** 99–102. (https://doi.org/10.18502/jost.v5i4.4379)

76 Wang B, Ye T, Zhang B, *et al.* Relationship of fracture morphological characteristics with posterolateral corner injuries in hyperextension varus tibial plateau fractures. *J Bone Joint Surg Am* 2024 **106** 2001–2008. (https://doi.org/10.2106/jbjs.23.01274)

77 Fardis Vosoughi IMO, Rahimdoost N, Kasaeian A, *et al.* Intrarater and inter-rater reliability of tibial plateau fracture classifications systematic review and meta analysis. *J Bone Joint Surg Am* 2024 **9** e23.00181. (https://doi.org/10.2106/jbjs.oa.23.00181)

78 Duparc J & Cavagna R. Results of the surgical treatment of fractures of the tibial plateau (apropos of 110 cases). *Int Orthop* 1987 **11** 205–213. (https://doi.org/10.1007/bf00271450)

79 Chang SM, Wang X, Zhou JQ, *et al.* Posterior coronal plating of bicondylar tibial plateau fractures through posteromedial and anterolateral approaches in a healthy floating supine position. *Orthopedics* 2012 **35** 583–588. (https://doi.org/10.3928/01477447-20120621-03)

EFORT Open Reviews (2025) **10** 316–326
https://doi.org/10.1530/EOR-2024-0184

80 Chang S-M, Zhang Y-Q, Yao M-W, *et al.* Schatzker type IV medial tibial plateau fractures: a computed tomography–based morphological subclassification. *Orthopedics* 2014 **37** e699–e706. (https://doi.org/10.3928/01477447-20140728-55)

81 Sun H, Zhai QL, Xu YF, *et al.* Combined approaches for fixation of Schatzker type II tibial plateau fractures involving the posterolateral column: a prospective observational cohort study. *Arch Orthop Trauma Surg* 2015 **135** 209–221. (https://doi.org/10.1007/s00402-014-2131-4)

82 Martínez-Rondanelli A, Escobar-González SS, Henao-Alzate A, *et al.* Reliability of a four-column classification for tibial plateau fractures. *Int Orthop* 2017 **41** 1881–1886. (https://doi.org/10.1007/s00264-017-3543-x)

83 Meinberg EG, Agel J, Roberts CS, *et al.* Fracture and dislocation classification compendium-2018. *J Orthop Trauma* 2018 **32** (Supplement 1) S1–S10. (https://doi.org/10.1097/bot.0000000000001063)

84 Anwar A, Zhang Y, Zhao Z, *et al.* Two column classification of tibial plateau fractures; description, clinical application and reliability. *Injury* 2019 **50** 1247–1255. (https://doi.org/10.1016/j.injury.2019.04.021)

85 Bernholt DL, DePhillipo NN, Grantham WJ, *et al.* Morphologic variants of posterolateral tibial plateau impaction fractures in the setting of primary anterior cruciate ligament tear. *Am J Sports Med* 2020 **48** 318–325. (https://doi.org/10.1177/0363546519893709)

86 Zhang X, Tian X, Wang S, *et al.* Different patterns of tibial plateau fractures associated with hyperextension injuries of the knee with or without varus/valgus component. *Medicine* 2021 **100** E28337. (https://doi.org/10.1097/md.0000000000028337)