WHAT REALLY CHANGES WITH CT IN TIBIAL PLATEAU AND PILON FRACTURES: A REVIEW OF CHANGES IN THE SURGICAL PLAN

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INTRODUCTION

Tibial plateau and pilon fractures are among the most complex injuries of the musculoskeletal system. Both types of fractures are characterized by a high degree of intra-articular involvement, instability, frequent associated soft-tissue injuries, and high rates of complications, including post-traumatic osteoarthritis. Over the past 30 years, the role of computed tomography in the management of these injuries has fundamentally changed, from an adjunctive diagnostic method to a primary tool determining the treatment strategy, surgical approach, fixation method, and timing of surgery.

Historically, in the era of conventional radiography, treatment of these fractures was largely based on the surgeon's experience and ability to mentally reconstruct three-dimensional anatomy from two-dimensional images. The probability of errors was high: posterior fragments could be missed, the extent of intra-articular disruption could be underestimated, and the surgical approach could be planned incorrectly. The introduction of CT, particularly three-dimensional reconstruction, has fundamentally changed this situation. Current evidence suggests that CT examination can not only improve diagnostic accuracy but also shift a patient from conservative to operative treatment, influence the choice between single and dual approaches, affect the choice between plate fixation and external fixation, and ultimately improve functional outcomes.

This review focuses specifically on the clinical decision-making role of CT: the specific findings that alter the surgical decision, the mechanisms underlying this influence, the evidence regarding improved outcomes, and practical recommendations for clinical practice.

TIBIAL PLATEAU FRACTURES

The Classic Schatzker Classification and Its Limitations

The Schatzker classification, introduced in 1974, has served as a standard system for describing tibial plateau fractures for several decades. It is based on two-dimensional radiographs and identifies six fracture types, ranging from a simple lateral split fracture (type I) to a complex bicondylar fracture (type VI). The system is simple to use and provides sufficient interobserver and intraobserver reproducibility when applied to radiographic images.

However, the Schatzker system has a fundamental limitation: it was developed for two-dimensional imaging and does not adequately describe the posterior column and posterior fragments. Posterior fragments are known to occur much more frequently than initially assumed based on radiographic assessment. Studies have shown that, with targeted analysis of CT images, posterior components are identified in 25–70% of fractures that had been classified as Schatzker types I–VI on radiographs. In other words, the classic system systematically underestimates the anatomical complexity of these fractures.

CT-Based Reclassification: The Three-Column Concept

In response to these limitations, Kfuri and Schatzker proposed a revised concept in 2018, known as the three-column concept. It divides the tibial plateau into three columns: medial, lateral, and posterior. The posterior column is further divided into posteromedial and posterolateral components. This system is based on three-dimensional CT analysis and allows identification of anatomical components that are not visible on conventional radiographs.

Key finding: when CT images with three-dimensional reconstruction are analyzed, more than 27% of specific osseous injury patterns, such as central articular surface depression or unique split-comminution patterns, may not be visible on standard two-dimensional CT slices but can be clearly identified on 3D reconstructions. This suggests that CT examination itself may be incomplete without three-dimensional processing of the acquired data.

How CT Changes the Decision to Perform Surgery

Classical indications for surgery in tibial plateau fractures include: (1) lateral plateau displacement of more than 5 mm on radiographs or (2) articular surface depression of more than 5 mm. However, these criteria are based on two-dimensional images and may be inaccurate.

CT examination may change the initial decision from conservative to operative treatment in the following situations:

• Identification of posterior fragments that are not visible on radiographs. Even a relatively small posterior fragment may compromise the stability of the articular surface. If radiographs suggest that a patient is a candidate for conservative treatment but CT demonstrates significant posterior fragments associated with subluxation, operative treatment may be required.

• Detection of articular surface depression underestimated on radiographs. CT allows accurate measurement of the depth of depression at individual points of the articular surface. A patient with a 3-mm depression on radiographs may have a localized depression of up to 8 mm on CT.

• Identification of instability. If CT demonstrates a tendency of the plateau fragments toward displacement or subluxation, conservative treatment may be unsuccessful.

A prospective study published in 2025 reported that CT-based three-column classification changed the initial treatment plan in 31% of patients who had initially been assigned to conservative treatment. Following reassessment based on CT findings, these patients underwent operative treatment, and outcomes, assessed using the Rasmussen score, were significantly better than those observed in patients who remained on conservative treatment despite the CT findings.

Selection of the Surgical Approach

CT analysis determines the choice between a single approach, dual approaches, or combined approaches. Traditionally, an anterolateral approach has been used for lateral tibial plateau fractures, providing access to the lateral surface of the plateau and the articular surface. However, this approach does not provide adequate visualization or fixation of posterior fragments.

CT analysis demonstrates the location of posterior fragments, including whether they are posteromedial or posterolateral. Based on these findings, the required surgical approach can be determined.

CT-based principles for surgical approach selection:

• No posterior fragments → a single anterolateral approach is sufficient.

• Posterolateral fragments (reported in 64% of cases involving posterior fractures) → the anterolateral approach may be supplemented by a posterolateral Frosch approach, through the interval between the extensor digitorum communis and peroneal muscles.

• Posteromedial fragments → the anterolateral approach may be supplemented by a Lobenhoffer posteromedial approach or a direct posterior approach.

• Combined posteromedial and posterolateral fragments → combined anterolateral + posteromedial + posterolateral approaches may be required.

A study of surgical approach anatomy in posterior tibial plateau fractures reported that the most complex pattern, involving both posteromedial and posterolateral fragments, accounts for approximately 15–20% of all tibial plateau fractures. Attempting to treat these fractures through a single approach may result in incomplete reduction and secondary loss of reduction, with reported rates reaching 30%.

Selection of the Fixation Method

Until the last decade, the standard treatment was the use of a single lateral locking plate inserted through an anterolateral approach. However, CT analysis has demonstrated that, in cases involving posterior fragments and combined fracture patterns, additional posterior fixation may provide substantially better mechanical stability.

Dual plating: this involves placement of not only a lateral plate through the anterolateral approach but also an additional posteromedial plate through a posteromedial approach, or a posterior plate through a direct posterior approach. Studies have reported:

• With a single lateral plate, the rate of secondary loss of reduction of posterior fragments is approximately 20–30%.

• With dual plating, this rate decreases to approximately 5–10%.

• Functional outcomes, including Rasmussen scores, weight-bearing capacity, and knee range of motion, are substantially better with dual plating.

• Treatment costs increase because of the additional plate and surgical approach; however, this may be offset by a reduction in revision procedures.

CT allows the surgeon to predict which patients will require dual fixation during the preoperative planning stage, thereby saving operating-room time and resources.

Prediction of Functional Outcomes Based on CT Findings

A recent study published in 2025 demonstrated that the degree of articular surface depression measured on CT was directly correlated with functional outcomes. Patients with residual depression exceeding 4 mm after surgery demonstrated significantly worse Rasmussen scores throughout the follow-up period at 6, 12, 24, and 36 weeks compared with patients in whom residual depression did not exceed 2 mm. This indicates that preoperative CT analysis may help the surgeon determine the degree of articular surface restoration that is achievable and estimate the expected functional outcome.

PILON FRACTURES (DISTAL TIBIA / PILON FRACTURES)

Anatomy, Complexity, and the Role of Three-Dimensional CT

Pilon fractures of the distal tibia are intra-articular fractures of the ankle joint in which the fracture extends through the distal tibia from the level of the syndesmosis to the articular surface. These fractures are characterized by:

• A high degree of intra-articular involvement, with almost 100% of fractures involving the articular surface.

• Complex three-dimensional geometry. The articular surface is inclined and concave, and each fragment must be accurately reduced.

• Frequent intercalary fragments, consisting of intermediate bone fragments impacted between larger fragments and often poorly visualized on conventional radiographic projections.

• Frequent soft-tissue injury. Of particular importance are the posterior tibial artery and tibial nerve, which pass through the tarsal tunnel posterior to the medial malleolus.

Conventional radiography of the distal tibia is often insufficiently informative. Anteroposterior and lateral projections do not adequately demonstrate the anatomical details of the central and posterior portions of the fracture or the true degree of displacement. Consequently, the role of CT in these injuries is disproportionately important.

Three-dimensional CT reconstruction allows the surgeon to: (1) rotate the image freely and visualize the fracture from multiple perspectives, (2) identify each fragment and determine its exact position, (3) calculate the optimal surgical approach, and (4) plan internal fixation before surgery.

CT-Based Classification and the Limitations of Earlier Systems

The classic Rüedi–Allgöwer classification divides pilon fractures into three types according to the degree of comminution. However, this system was developed for radiographic assessment and does not adequately reflect the anatomical complexity of these injuries. A study in which the same fracture was evaluated using radiographs and CT demonstrated low agreement between the two imaging modalities: the same fracture could be classified differently depending on the imaging technique used.

A more contemporary approach involves CT-based classification systems that take into account the location of fracture fragments in multiple planes. This allows not only more accurate prediction of fracture complexity but also determination of the optimal surgical strategy.

Selection of the Surgical Approach Based on CT Analysis

Unlike tibial plateau fractures, in which approach selection is primarily determined within the medial-lateral plane, pilon fractures may require anterior, lateral, or posterior approaches depending on the specific fracture pattern.

Anterior Approaches (Anteromedial and Anterolateral Approaches)

These approaches are used for fractures involving the main central portion of the articular surface. They provide good visualization of the articular surface and anterior fragments. Their main limitation is inadequate visualization of posterior fragments.

Lateral Approach (Fibular Approach)

This approach may be used when the majority of the fracture fragments are located posterolaterally. It is technically less demanding than a posterior approach and may be less traumatic to the soft tissues.

Posterior Approaches

Posterior fragments are reported in almost 70% of pilon fractures. CT provides precise localization of these fragments:

• When the posterior fragment is located posterolaterally (>64% of cases), a posterolateral approach may be used, allowing adequate access while minimizing the risk of injury to the deep peroneal nerve.

• When the fragment involves the medial shoulder or is located close to the midline, a posteromedial or direct posterior approach may be used.

• **Critical finding:** CT may demonstrate whether the posterior tibial artery, tibial nerve, or tendons are entrapped between fracture fragments. When these structures are entrapped, direct surgical access may be required to release them and prevent vascular or neurological compromise.

A study comparing medial and lateral approaches for posterior pilon fractures demonstrated that approach selection substantially affects the adequacy of reduction. When a suboptimal approach is selected, medial components may remain unreduced, resulting in residual articular incongruity and malalignment of the ankle joint.

CT and Selection of the Stabilization Method

Two decades ago, external fixation throughout the entire period of fracture healing was one of the principal treatment methods for severe pilon fractures. However, this strategy was associated with a high rate of complications, including ankle contractures, restricted motion, and pin-site infections.

Modern treatment increasingly relies on internal fixation, while CT analysis helps determine the optimal fixation strategy:

• Simple fractures without intercalary fragments → a single anteromedial plate or combined anterior approach.

• Fractures with posterolateral components → a combination of anterior plate fixation and a posterior plate through a posterior approach.

• Fractures with critical soft-tissue injury or segmental bone loss → temporary external fixation followed by delayed internal fixation, usually after 7–10 days when soft-tissue conditions have improved.

This strategy can be determined during CT-based preoperative planning, allowing the surgical team to prepare the necessary implants and instrumentation before the procedure.

CT and Timing of Surgery

CT analysis contributes to determining the appropriate timing of surgery. In general, definitive fixation is recommended after approximately 1–2 weeks, when soft-tissue swelling begins to resolve. However, CT and clinical assessment may identify situations in which immediate surgery is unsafe:

• Severe skin injury, fracture blisters, or disruption of the skin and subcutaneous tissues → temporary stabilization with an external fixator for approximately 7–10 days before planned internal fixation.

• Massive soft-tissue swelling, in which surgical exposure would be excessively traumatic → delayed fixation is preferable.

MODERN TECHNOLOGIES: 3D PRINTING AND VIRTUAL REALITY

In recent years, additional technologies have emerged that expand the capabilities of CT in preoperative planning.

3D Printing

Three-dimensional printing allows creation of a physical model of the fracture using plastic or resin. The surgeon can hold the model, assess the reduction, plan plate positioning, and determine screw trajectories and angles. Studies have demonstrated that 3D printing:

• Reduces operative time by approximately 15–20%.

• Improves reduction accuracy and may reduce the need for revision surgery.

• Helps less experienced surgeons better understand complex anatomy and prepare for the procedure.

Virtual Reality

Virtual reality platforms allow surgeons to interact with three-dimensional fracture models, simulate fragment reduction, and assess visualization from different surgical approaches. A cadaveric study demonstrated that surgeons who trained using VR before performing procedures for complex tibial plateau fractures made fewer errors and completed reduction more rapidly.

PRACTICAL CONCLUSIONS AND RECOMMENDATIONS

Based on the available evidence, the following practical recommendations can be formulated:

For Tibial Plateau Fractures

1. CT examination with three-dimensional reconstruction should be routinely considered for tibial plateau fractures, rather than being reserved only for complex cases. The apparent savings associated with avoiding CT may be outweighed by the cost and morbidity of revision surgery.
2. CT assessment should systematically include:

• Presence or absence of posterior fragments. If posterior fragments are present, an additional surgical approach may be required.

• Depth of articular surface depression. Depression greater than 5 mm may require reduction and stabilization.

• Stability of the articular surface. If instability is demonstrated, operative treatment may be indicated even when displacement appears minimal on radiographs.

3. Expected change in treatment plan: if radiographs suggest conservative treatment but CT demonstrates posterior fragments or instability, operative treatment should be considered.
4. Dual plating may be required in the presence of significant posteromedial fragments or combined posteromedial and posterolateral components.

For Pilon Fractures

1. CT with three-dimensional reconstruction should be considered essential for complex pilon fractures. The Rüedi–Allgöwer classification based on radiographs may underestimate fracture complexity.
2. CT assessment should include:

• Location and number of fragments, including anterior, lateral, and posterior components.

• Presence of intercalary fragments.

• Soft-tissue involvement, including possible entrapment of vessels or nerves.

• Degree of articular surface destruction.

3. Surgical approach should be determined according to the location of the principal fracture fragments:

• Anterior fragments → anteromedial/anterolateral approach.
• Posterolateral fragments → lateral or posterolateral approach.
• Posteromedial fragments → posteromedial approach.
• Combined patterns → combined approaches.

4. In the presence of critical soft-tissue injury, staged treatment should be considered, consisting of temporary external fixation followed by definitive internal fixation.

General Recommendations

• CT examination should include 1–2-mm slices rather than 5-mm slices for tibial plateau and pilon fractures.

• Three-dimensional reconstruction should be performed whenever detailed fracture morphology and surgical planning are required. Two-dimensional images alone may be insufficient in complex injuries.

• In complex cases, the use of 3D printing or virtual reality-based planning should be considered.

• When feasible, a multidisciplinary surgical conference should be conducted to discuss the operative plan before surgery.

• The operative report should document how CT findings altered the initial treatment plan.

CONCLUSION

Computed tomography with three-dimensional reconstruction has fundamentally changed the management of tibial plateau and pilon fractures. CT can:

- Reclassify fractures by revealing more complex anatomical features than those suspected from radiographs.
- Change the treatment decision from conservative to operative management.
- Determine the optimal surgical approach.
- Predict the need for dual fixation.
- Contribute to prediction of functional outcomes.
- Guide the selection of surgical timing and stabilization strategy.

None of these functions can be performed reliably on the basis of conventional radiography or surgical intuition alone. Despite economic and organizational barriers, CT examination in these fractures should be regarded as a standard component of diagnostic assessment and preoperative planning rather than merely an additional imaging test.

Future directions include wider implementation of 3D printing and VR-based surgical planning, development of machine-learning models for automated fracture classification, and integration of these technologies into routine practice in regional trauma centers.

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