Schatzker Classification of Tibial Plateau Fractures: Use of CT and MR Imaging Improves Assessment[1]

CME FEATURE

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LEARNING OBJECTIVES FOR TEST 6

After reading this article and taking the test, the reader will be able to:

- Describe the Schatzker classification system for tibial plateau fractures.
- List the added benefits of cross-sectional imaging over plain radiography for preoperative assessment of tibial plateau fractures.
- Discuss the effects of the Schatzker classification on outcomes after treatment of tibial plateau fractures.

The Schatzker classification system for tibial plateau fractures is widely used by orthopedic surgeons to assess the initial injury, plan management, and predict prognosis. Many investigators have found that surgical plans based on plain radiographic findings were modified after preoperative computed tomography (CT) or magnetic resonance (MR) imaging. The Schatzker classification divides tibial plateau fractures into six types: lateral plateau fracture without depression (type I), lateral plateau fracture with depression (type II), compression fracture of the lateral (type IIIA) or central (type IIIB) plateau, medial plateau fracture (type IV), bicondylar plateau fracture (type V), and plateau fracture with diaphyseal discontinuity (type VI). Management of type I, II, and III fractures centers on evaluating and repairing the articular cartilage. The fracture-dislocation mechanism of type IV fractures increases the likelihood of injury to the peroneal nerve or popliteal vessels. In type V and VI fractures, the location of soft-tissue injury dictates the surgical approach and the degree of soft-tissue swelling dictates the timing of definitive surgery and the need for provisional stabilization with an external fixator. CT and MR imaging are more accurate than plain radiography for Schatzker classification of tibial plateau fractures, and use of cross-sectional imaging can improve surgical planning.

TEACHING POINTS

See last page

Abbreviations: ACL = anterior cruciate ligament, LCL = lateral collateral ligament, MCL = medial collateral ligament, PCL = posterior cruciate ligament

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Introduction

Tibial plateau fractures may occur together with meniscal and ligamentous injuries to the knee. Although certain injury patterns may suggest a predominantly osseous injury to the knee, others may suggest significant soft-tissue injury. Standard tibial plateau fractures involve cortical interruption or depression or displacement of the articular surfaces of the proximal tibia without concomitant significant injury to the capsule or ligaments of the knee (1). On the basis of plain radiographic findings, the prevalence of ligament injury in these types of fractures is approximately 20%–30% (2,3).

On the other hand, an avulsion fracture with or without a tibial condyle facture is more typical of a fracture-dislocation. The prevalence of ligament injury in fracture-dislocations is much higher, between 60% and 100% (4,5). The absence of any obvious osseous injury may suggest a pure knee dislocation or distraction injury, which is defined as a pure ligamentocapsular injury (1). The Schatzker classification system focuses on standard tibial plateau fractures. However, higher Schatzker fracture rankings may represent fracture-dislocations and are predictive of significant associated soft-tissue injury.

The Schatzker classification is based on the idea that "certain pathoanatomic and etiological factors as well as therapeutic features demand that certain injury types be grouped together" (2,3). In the Schatzker classification, each increasing numeric fracture category indicates increasing severity, reflecting not only increased energy imparted to the bone at the time of injury but also an increasingly worse prognosis. Therefore, orthopedic surgeons find the Schatzker classification useful in assessing the initial injury, planning management, and predicting prognosis.

Many authors have reported that initial Schatzker rankings and surgical plans based on plain radiographic findings were modified after preoperative computed tomography (CT) or magnetic resonance (MR) imaging (6–8). In this article, we describe the added benefit of CT and MR imaging for correct characterization of tibial plateau fractures and discuss how fracture management and outcome change with each Schatzker fracture type.

Schatzker Fracture Types

The Schatzker classification system divides tibial plateau fractures into six types: lateral tibial plateau fracture without depression (I), lateral tibial plateau fracture with depression (II), compression fracture of the lateral (IIIA) or central (IIIB) tibial plateau, medial tibial plateau fracture (IV), bicondylar tibial plateau fracture (V), and tibial plateau fracture with diaphyseal discontinuity (VI). The first three types (I, II, and III) are typically the result of low-energy injury (9,10). The second three types (IV, V, and VI) are typically the result of high-energy injury. However, relatively low-energy trauma to osteoporotic bones may produce fracture patterns similar to those of high-velocity injuries (11). The magnitude of the force determines both the degree of fragmentation and the degree of displacement (9). The frequency and type of associated soft-tissue injury and the surgical approach vary by fracture type and are discussed under each fracture type.

Type I Fracture

A Schatzker type I fracture is a wedge-shaped pure cleavage fracture of the lateral tibial plateau, originally defined as having less than 4 mm of depression or displacement (2,3). Depression may be difficult to measure on plain radiographs, and type I fractures may look like type II fractures (Fig 1) or vice versa. Type I fractures may also be very subtle at plain radiography (Fig 2). These fractures are caused by the lateral femoral condyle being driven into the articular surface of the tibial plateau; they represent 6% of all tibial plateau fractures and are more frequent in young patients with normal bone mineralization.

In general, impaction injury to one side of the knee is associated with distraction injury to the opposite side of the knee. The mechanism of injury in type I fractures involves valgus force

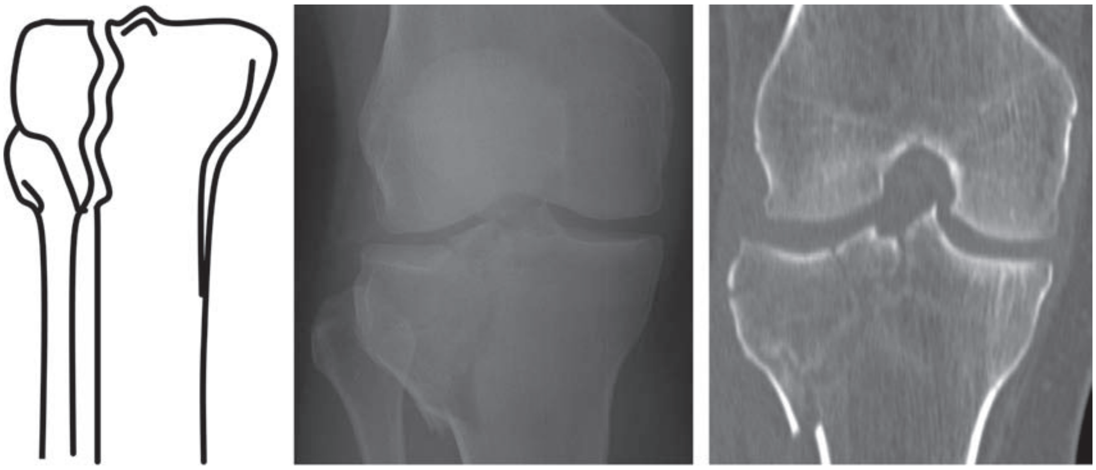

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Figure 1. Type I fracture in a 50-year-old man who was in a motorcycle accident. **(a)** Diagram shows a Schatzker type I fracture. **(b)** Plain radiograph shows a split fracture of the lateral tibial plateau with possible depression. **(c)** Coronal CT image shows no depression of the tibial plateau, a finding consistent with a type I fracture. No depression was evident at surgery. The fracture was reduced and fixed with a lateral compression plate.

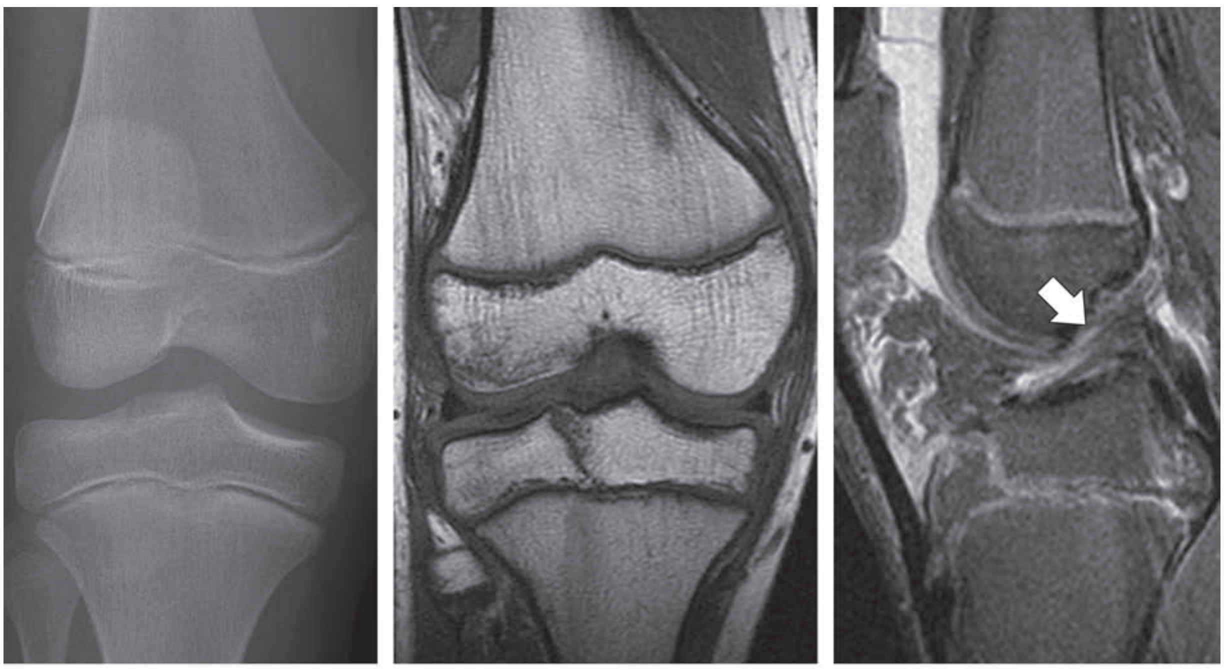

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Figure 2. Type I fracture in a 12-year-old boy who experienced trauma to the lateral knee. **(a)** Plain radiograph shows a cortical break at the medial aspect of the lateral tibial plateau, a finding suggestive of a nondisplaced fracture. **(b)** Coronal proton-density–weighted MR image shows a lateral tibial plateau fracture. **(c)** Sagittal T2-weighted MR image shows an indistinct anterior cruciate ligament (ACL) with increased signal intensity (arrow), a finding compatible with a partial tear. The fracture was treated conservatively with absence of weight bearing and with knee immobilization.

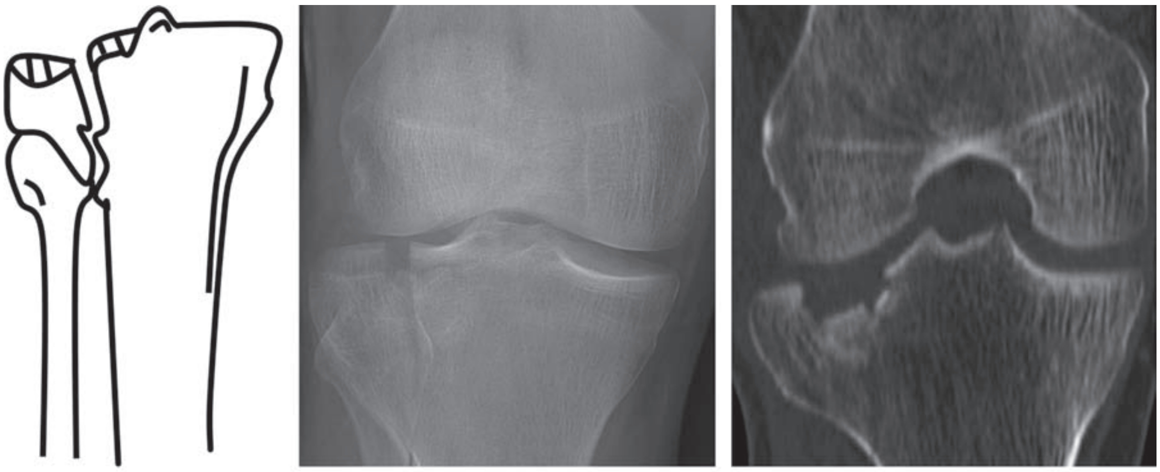

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Figure 3. Type II fracture in a 48-year-old man who was in a snowmobile accident. **(a)** Diagram shows a Schatzker type II fracture. **(b)** Plain radiograph shows separation of the tibial plateau with subtle depression, a finding that might be mistaken for a type I fracture. **(c)** Coronal CT image shows 4 mm of depression, a finding indicative of a type II fracture. Cartilage depression was confirmed at surgery, and the depressed portion of the plateau was elevated and fixed.

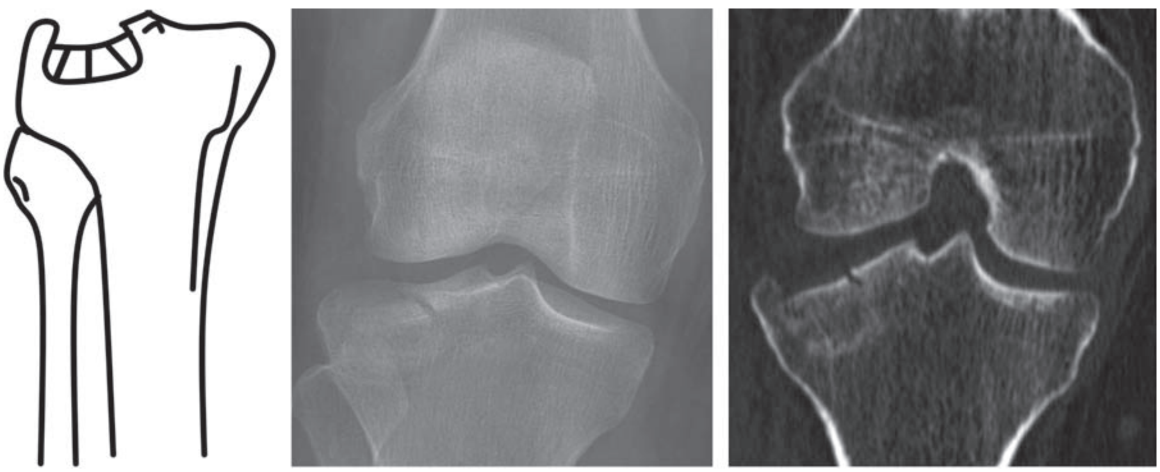

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Figure 4. Type IIIA fracture in a 55-year-old woman who fell on ice and injured her knee. **(a)** Diagram shows a Schatzker type IIIA fracture. **(b)** Plain radiograph shows depression of the lateral tibial plateau. **(c)** Coronal CT image shows the lateral tibial plateau depression. The fracture was managed nonoperatively with no weight bearing for 12 weeks.

combined with axial loading on the knee and therefore may be associated with a distraction-type injury to the medial collateral ligament (MCL) or ACL (Fig 2).

The aim of treatment is to achieve a stable, aligned, mobile, and painless joint and to minimize the risk of posttraumatic osteoarthritis. Treatment options include open reduction and internal fixation with or without arthroscopy. If the meniscus is intact at arthroscopy, closed reduction with percutaneous fixation is considered. Type I fractures can be fixed with two transverse cancellous screws.

Type II Fracture

A Schatzker type II fracture is a combined cleavage and compression fracture of the lateral tibial plateau, a type I fracture with a depressed

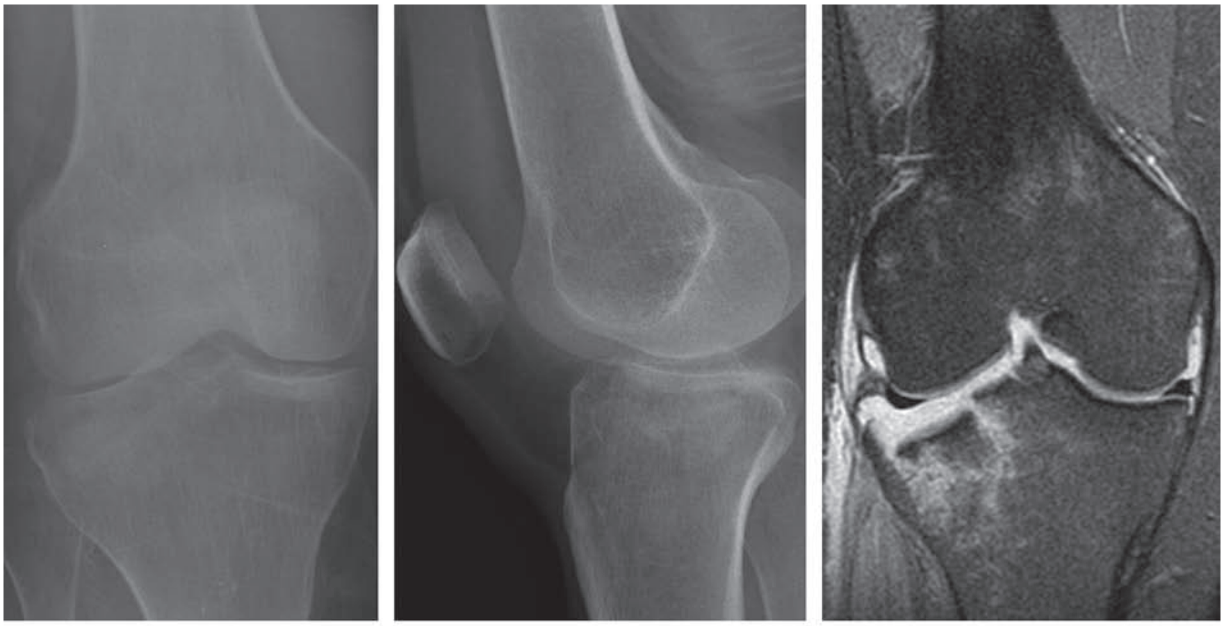

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Figure 5. Type IIIA fracture in a 31-year-old woman who was in a motor vehicle accident. **(a, b)** Posteroanterior **(a)** and lateral **(b)** radiographs show ill-defined increased opacity at the subarticular lateral tibial plateau and a large joint effusion. These findings are suggestive of a depressed fracture of the lateral tibial plateau, a Schatzker type IIIA fracture. **(c)** Coronal T2-weighted MR image shows depression of the tibial articular cartilage; the depression is more extensive than indicated on the radiographs. A possible injury to the suspensory ligament of the lateral meniscus is also suggested.

component. Depression may not be appreciated on plain radiographs, and type II fractures may look like type I fractures (Fig 3). Tibial plateau depression is measured as the vertical distance between the lowest point on the intact medial plateau and the lowest depressed lateral plateau fracture fragment. Schatzker et al (2) originally defined depression as measuring greater than 4 mm. These fractures represent 25% of all tibial plateau fractures and are more frequent in patient populations in the 4th decade of life or later because a degree of osteopenia is typically required for depression to occur. The mechanism of injury involves valgus force on the knee, and 20% of patients have associated distraction injuries to the MCL or medial meniscus. Formal open treatment is often performed for all unstable fractures of the tibial plateau.

Type III Fracture

A Schatzker type III fracture is a pure compression fracture of the lateral tibial plateau in which the articular surface of the tibial plateau is depressed and driven into the lateral tibial metaphysis by axial forces (Fig 4). Occasionally, depression may not be immediately evident on plain radiographs and may be clearly demonstrated only at cross-sectional imaging (Figs 5, 6). These fractures represent 36% of all tibial plateau fractures and are more frequent in the older age groups (the 4th and 5th decades of life), in whom some degree of osteopenia is more likely to occur.

Type III fractures are divided into two subtypes: those with lateral depression (type IIIA) (Figs 4, 5) and those with central depression (type IIIB) (Fig 6). Joint stability is rarely affected in type III fractures, but axial instability may occasionally occur in type IIIB fractures. Treatment for type IIIA fractures may be nonoperative if the extent of articular depression is small and the joint remains stable. A type IIIB fracture may result in joint instability, in which case the depressed portion of the plateau is typically elevated by means of a submetaphyseal cortical window (12). Arthroscopic reduction of type III fractures is also possible (Fig 6). Although arthroscopic assistance is frequently employed for Schatzker

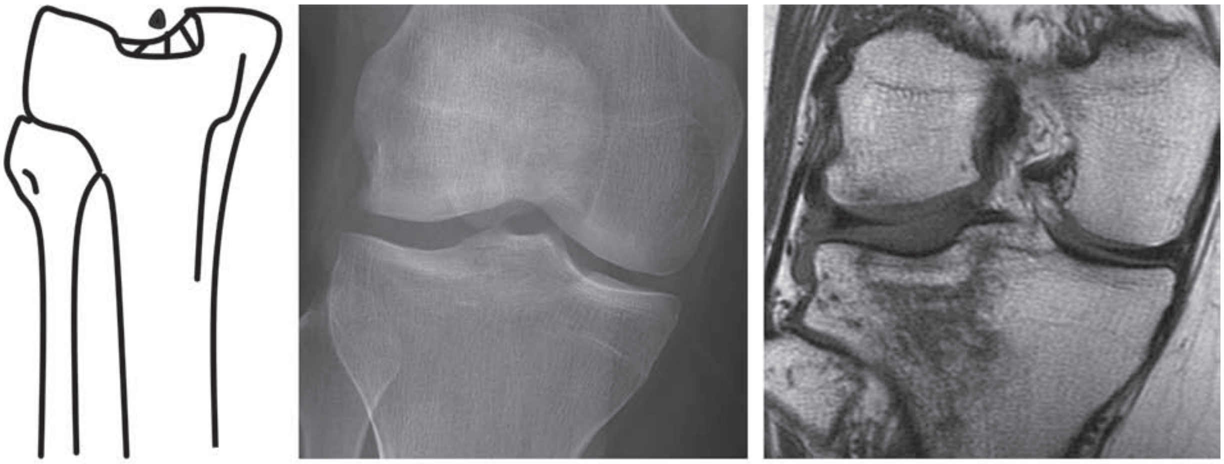

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Figure 6. Type IIIB fracture in an 18-year-old man who fell and twisted his knee while building shelves. **(a)** Diagram shows a Schatzker type IIIB fracture. **(b)** Plain radiograph shows a subtle fracture of the anterior tibial spine. **(c)** Coronal proton-density–weighted MR image shows a compression fracture of the intercondylar eminences and the central aspect of the lateral tibial plateau, a type IIIB fracture. **(d)** Sagittal T2-weighted MR image shows an associated avulsion injury of the ACL (arrow). Arthroscopic reduction was performed with internal fixation of the tibial plateau and tibial spine fractures.

type I and type III fractures to assess for and occasionally reduce injury to the cartilage, it is less commonly employed for type II, IV, V, and VI fractures.

Teaching Point

Management of type I, II, and III fractures centers on evaluating and repairing the articular cartilage.

Type IV Fracture

A Schatzker type IV fracture is a medial tibial plateau fracture with a split or depressed component (Fig 7). The mechanism of injury involves varus force with axial loading at the knee (3,4). Posteromedial coronal split fractures occur as a result of varus forces combined with axial loading in a hyperflexed knee (1). These fractures represent 10% of all tibial plateau fractures and carry the worst prognosis. Younger patients tend to have a high-energy mechanism of injury and commonly have a component of subluxation or dislocation that reduces spontaneously. Owing to the subluxation or dislocation, cross-sectional imaging may be more accurate than standard radiography for assessment of fracture extent (Fig 8).

Teaching Point

The fracture-dislocation mechanism of type IV fractures increases the likelihood of injury to the peroneal nerve or popliteal vessels (12). This fracture is also frequently associated with distraction injury to the lateral compartment, resulting in lateral collateral ligament (LCL) complex or posterolateral corner injury or in fracture or dislocation of the proximal fibula (13). Older patients may sustain a type IV fracture from a low-energy force. In such cases, fracture-dislocation and associated soft-tissue injuries may not occur.

In Schatzker type IV fractures, the risk of compromise to the popliteal artery and peroneal nerve is significant and should direct initial therapy. Type IV fractures tend to angulate into varus position and are typically treated by means of open reduction and internal fixation with a medial buttress plate and cancellous screws (8).

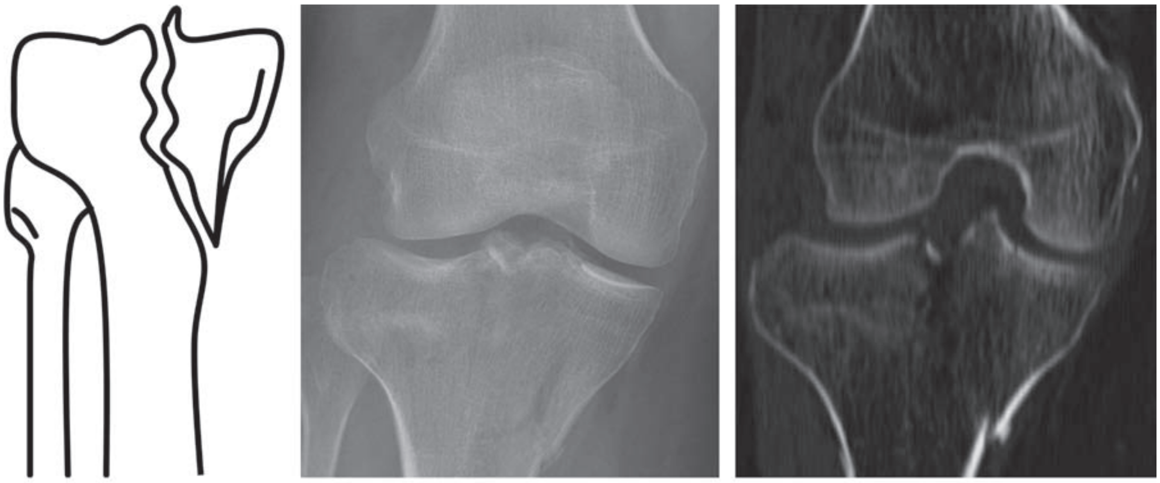

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Figure 7. Type IV fracture in a 51-year-old woman who was in a high-speed motorcycle collision. **(a)** Diagram shows a Schatzker type IV fracture. **(b)** Plain radiograph shows a split fracture of the medial tibial plateau with medial subluxation of the knee. **(c)** Coronal CT image shows the medial tibial plateau fracture and medial subluxation. Initially, the fracture was reduced with placement of a spanning external fixator because of significant soft-tissue swelling and concern about vascular compromise. Surgical reduction and internal fixation were performed once the swelling had resolved.

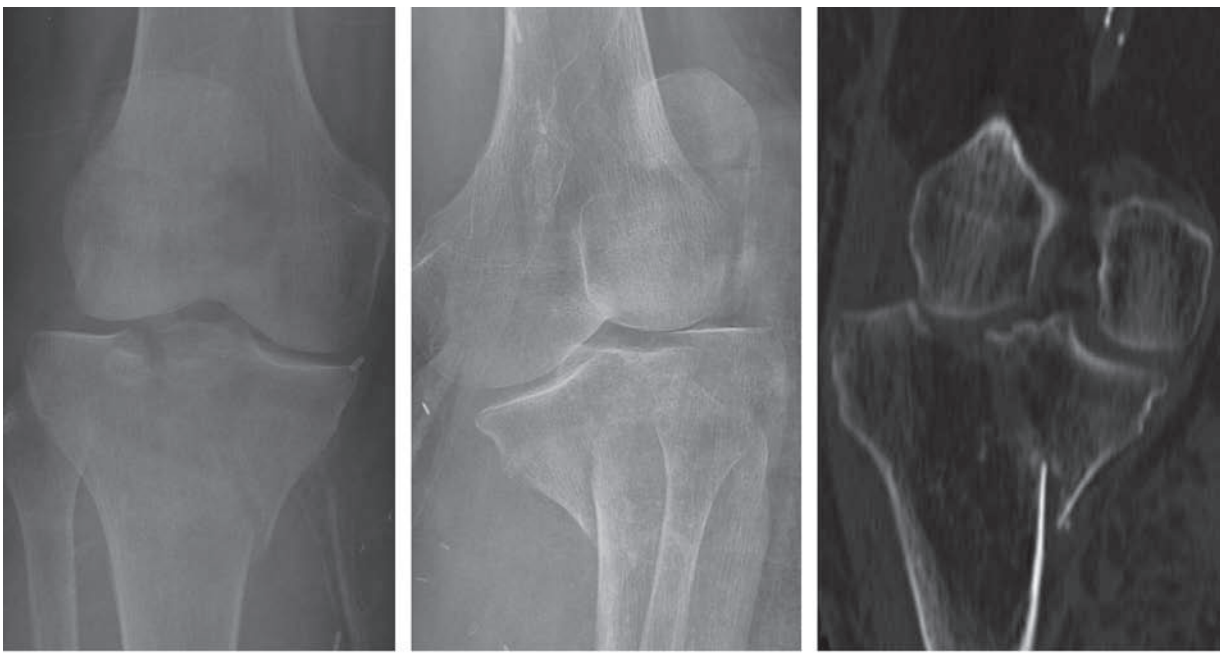

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Figure 8. Type IV fracture in an 80-year-old woman who was in a motor vehicle accident and presented with open fractures of the knee. **(a, b)** Posteroanterior **(a)** and lateral **(b)** radiographs of the knee show an appearance suggestive of a bicondylar tibial plateau fracture (Schatzker type V fracture). A fracture of the patella is also noted. **(c)** Coronal CT image shows only a fracture of the medial tibial plateau, a type IV fracture. There is also lateral subluxation. Initially, the open fractures were irrigated and débrided, and an external fixator was placed. Subsequently, definitive surgical reduction and internal fixation along with partial patellectomy were performed.

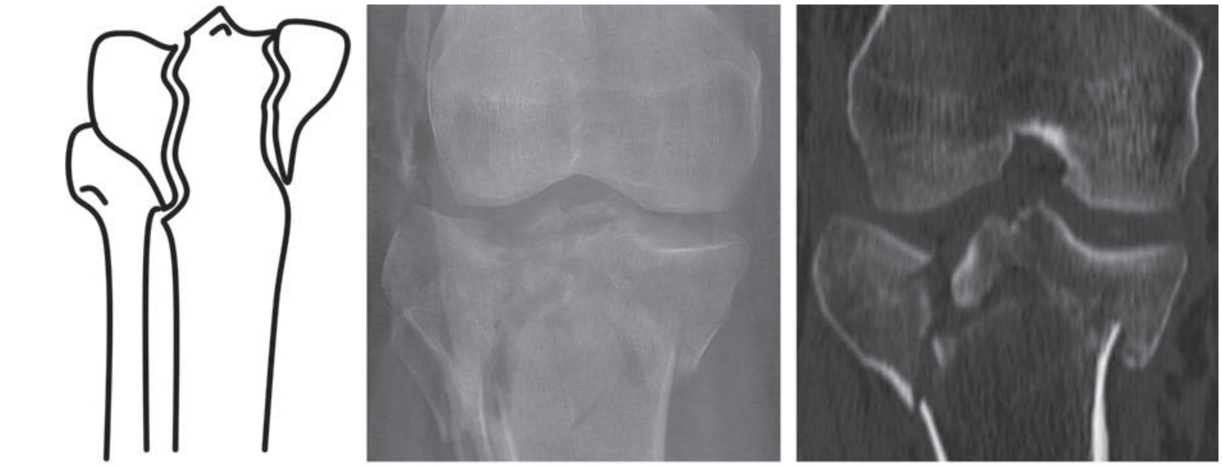

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Figure 9. Type V fracture in a 60-year-old man who fell 12 ft (3.6 m) off a ladder onto his knee while trimming trees. **(a)** Diagram shows a Schatzker type V fracture. **(b)** Plain radiograph shows a bicondylar split fracture. **(c)** Coronal CT image shows the bicondylar split fracture. Physical examination showed no evidence of neurovascular compromise. Initially, the fracture was reduced with placement of a spanning external fixator because of significant soft-tissue swelling. Once the swelling had resolved, definitive surgical reduction and internal fixation were performed with double buttress plating.

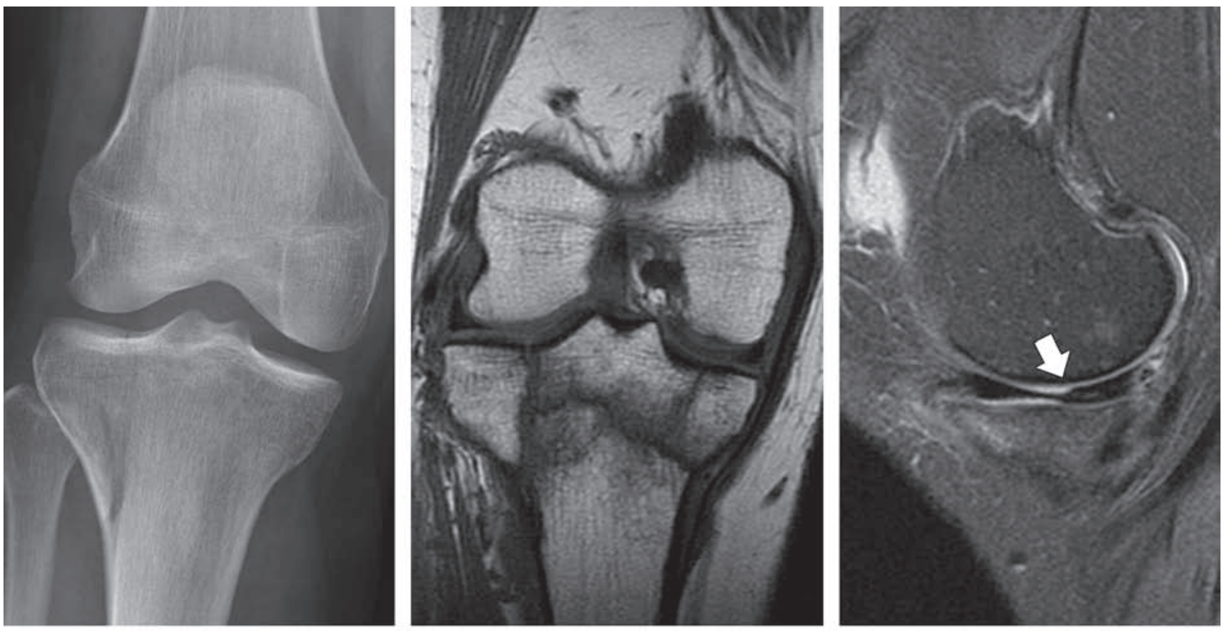

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Figure 10. Four-part fracture in a 41-year-old woman who was involved in an altercation. **(a)** Plain radiograph shows a split fracture of the lateral tibial plateau. Initially, the fracture was treated conservatively with absence of weight bearing. MR imaging was performed because of continued pain and swelling and clinical suspicion of a meniscal or ligamentous injury. **(b)** Coronal proton-density–weighted MR image shows an unsuspected nondepressed four-part fracture of the tibial plateau. **(c)** Sagittal T2-weighted MR image shows contour irregularity and abnormal high signal intensity of the medial meniscus (arrow), findings compatible with a tear.

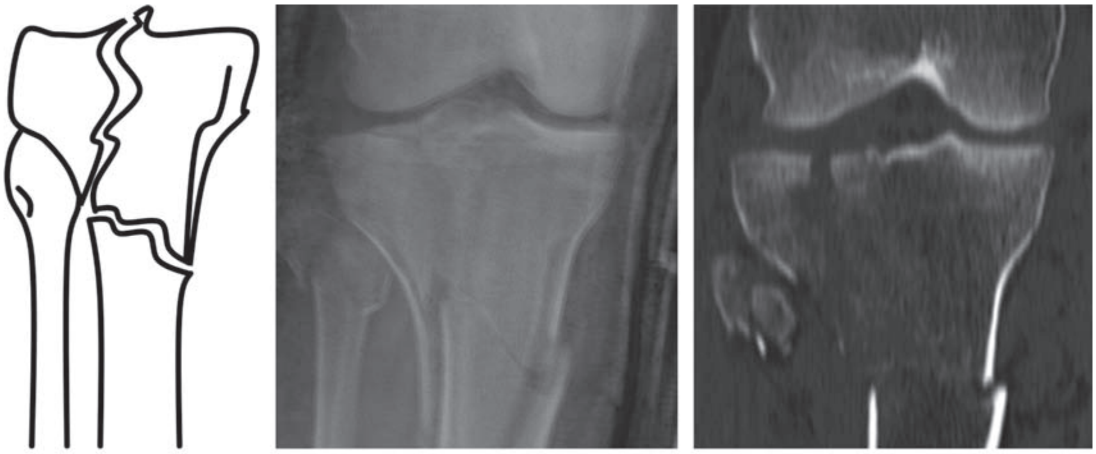

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Figure 11. Type VI fracture in a 43-year-old woman who fell down a flight of stairs. **(a)** Diagram shows a Schatzker type VI fracture. **(b)** Plain radiograph shows a metaphyseal-diaphyseal fracture with apparent extension into the joint space. **(c)** Coronal CT image shows the lateral split fracture component of the type VI tibial plateau fracture. Initially, the fracture was reduced with placement of a spanning external fixator because of significant soft-tissue swelling. Once the swelling had resolved, definitive surgical reduction and internal fixation were performed.

Type V Fracture

A Schatzker type V fracture consists of a wedge fracture of the medial and lateral tibial plateau, often with an inverted "Y" appearance (Fig 9). Articular depression is typically seen in the lateral plateau, and there may be associated fracture of the intercondylar eminence. Type V fractures are distinguished from type VI fracture patterns by the maintenance of metaphyseal-diaphyseal continuity.

These fractures represent only 3% of all tibial plateau fractures and are typically associated with a high-energy mechanism of injury, such as a motor vehicle collision. The mechanism of injury tends to be complex, involving a combination of varus or valgus stresses combined with axial loading (4,5,13). Up to one-half of patients with type V fractures have peripheral meniscal detachment, and one-third have ACL avulsion injury.

Condylar fractures cause instability by disrupting the anchor of the collateral ligaments. Injury to the collateral ligaments themselves may not be clinically significant. In bicondylar fractures, the cruciate ligaments become crucial for joint stability. Additional fracture of the intercondylar eminence is referred to as a four-part fracture and renders the knee unstable due to loss of the cruciate ligament anchor (Fig 10) (12). Further evaluation of bicondylar fractures with cross-sectional imaging may be helpful to exclude unstable four-part fractures.

Initial management involves splinting or temporary external fixation. To reduce the risk of infection, it is customary to wait for soft-tissue inflammation and edema to subside before surgical management (Fig 9). Many of these fractures are not treated with internal fixation at all because of the risks of complication. In a case review study of tibial plateau fractures, Moore et al (14) found that 23% of Schatzker type V fractures became infected after treatment. In their series, 82% of the fractures that required both medial and lateral plating were complicated by wound dehiscence or infection. More recent studies have found that use of two-incision techniques can reduce infection rates to around 12% (15).

Type VI Fracture

The key feature of a Schatzker type VI fracture is a transverse subcondylar fracture with dissociation of the metaphysis from the diaphysis (Fig 11). The fracture pattern of the condyles is variable, and all types of fractures can occur. These fractures represent 20% of all tibial plateau fractures and are the result of high-energy injury to the knee. The mechanism of injury is complex, similar to type V fractures. One-third of type VI fractures are open, and frequently there is extensive soft-tissue injury with increased risk of compartment syndrome.

The dissociation between the metaphysis and diaphysis makes this fracture unsuitable for treatment with traction. Most such fractures are treated with buttress plates and, if both condyles are fractured, cancellous screws on either side (12). In Schatzker type V and VI fractures, the status of the soft tissues dictates management options.

Teaching Point

Diagnosis of Tibial Plateau Fractures

In many cases, CT findings mirror those of conventional radiography. However, studies of tibial plateau fractures have shown that surgical plans based on plain radiographic findings are modified in 6%–60% of cases after CT and 21% of cases after MR imaging (6–8). In fact, Yacoubian et al (7) found that results of preoperative fracture assessment with MR imaging had 100% agreement with the surgical findings in 54 cases. Cross-sectional imaging results change surgical plans based on plain radiographic findings by more precisely demonstrating the fracture pattern, depression, and displacement (6–8).

Fracture depression and displacement are the most important factors affecting surgical management of standard tibial plateau fractures. If left untreated, depression results in joint incongruity, valgus deformity, and a sense of instability. In addition, in displaced fractures, the meniscus may be torn and wedged into the fracture site, requiring arthrotomy, disimpaction, and repair. For this reason, Bennett and Browner (16) recommend arthroscopic evaluation of all surgically treated Schatzker type I fractures to ensure that the lateral meniscus is not trapped within the fracture site. As illustrated by several examples in this article, fracture depression and displacement are frequently misrepresented on plain radiographs, and cross-sectional imaging usually provides more reliable information (Figs 1, 3, 5, 6). The need for accurate assessment of fracture depression and displacement is a major reason why CT has become the current standard for preoperative evaluation of bone injury.

Schatzker et al (2) originally defined depression as being greater than 4 mm. Unfortunately, there are no accurate data on the amount of articular depression and displacement that can be accepted. As little as 2 mm of depression may be considered significant in young patients and athletes. On the other hand, up to 5 mm of depression has been tolerated in some studies, as long as alignment and stability are maintained (16). Studies that evaluated the long-term development of secondary osteoarthritis showed no statistical difference between less than 2 mm of depression and less than 4 mm (17). Animal studies have demonstrated development of osteoarthritis when the step-off from the articular surface exceeds the thickness of the articular cartilage (18).

Kode et al (19) compared MR imaging with CT for evaluation of tibial plateau fractures and found that MR imaging was equivalent or better in determining the degree of fracture displacement. Friemert et al (20) prospectively compared arthroscopic findings of 156 cartilage lesions with MR imaging findings to determine if MR imaging could feasibly replace arthroscopy in diagnosis of cartilage damage. They found that MR imaging had high specificity (97%–99%) and high negative predictive value (97%–98%) for cartilage lesions and concluded that MR imaging is suitable for the exclusion of cartilage lesions.

Diagnosis of Associated Soft-Tissue Injuries

Orthopedic surgeons have traditionally relied on physical examination, surgical findings, and arthroscopy for detection of ligament injury. In fact, a composite history and physical examination may be highly predictive of ACL or posterior cruciate ligament (PCL) tear (21). Recently, however, orthopedists have increasingly accepted CT and MR imaging for preoperative assessment of soft-tissue injury, especially if there is a tibial plateau fracture. Gardner et al (22) evaluated preoperative MR imaging results in 103 patients with all types of tibial plateau fractures and found that the overall prevalence of injury to soft tissues was higher than previously reported. Only 1% of patients had complete absence of any soft-tissue injury; 77% had a complete tear or avulsion of one or more cruciate or collateral ligaments, and 68% had tears of one or more of the posterolateral corner structures of the knee. Currently, the clinical significance of preoperative diagnosis of meniscal and ligamentous injury is unknown, but diagnostic imaging may prove helpful for surgical planning in the future.

A recent systematic review of 59 articles that reported the results of 7367 MR imaging examinations and 5416 arthroscopic procedures

RadioGraphics

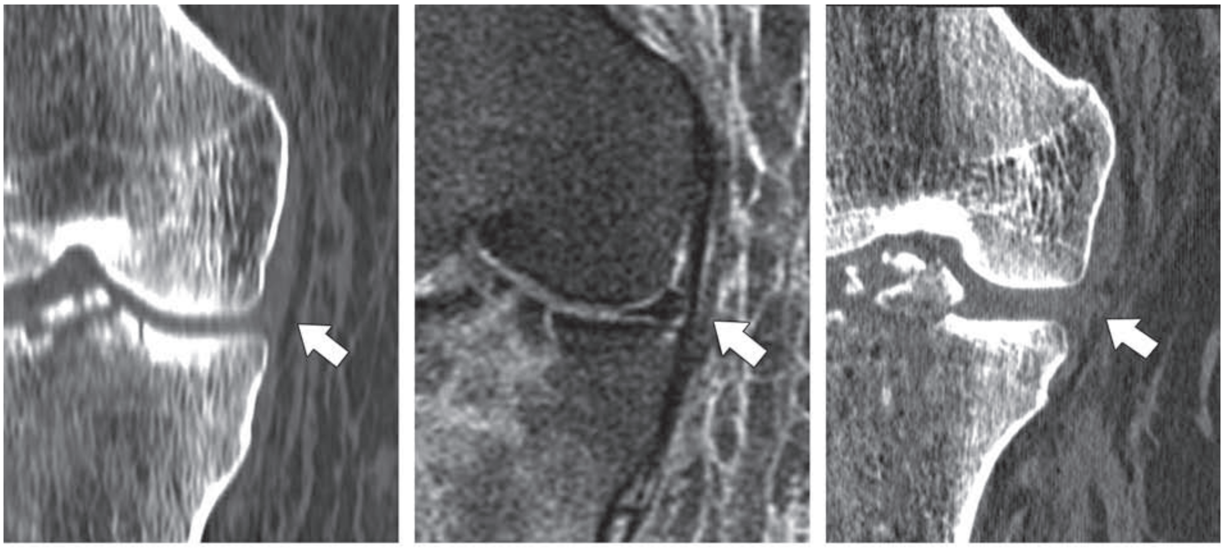

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Figure 12. Evaluation of MCL integrity in two patients with tibial plateau fractures. **(a, b)** Coronal CT **(a)** and T2-weighted MR **(b)** images of a 34-year-old patient, who was struck by a motor vehicle while in a crosswalk, show a type IV fracture (incompletely seen). The MCL has a smooth contour on the CT image (arrow in **a**) and is intact on the MR image (arrow in **b**). **(c, d)** Coronal CT **(c)** and T2-weighted MR **(d)** images of a 19-year-old woman, who injured her knee while jumping on a trampoline, show a type VI fracture (incompletely seen). The MCL has an irregular contour on the CT image (arrow in **c**) and is completely torn on the MR image (arrow in **d**). MR imaging also demonstrated injury to the ACL and PCL and a lateral meniscocapsular separation. All of these injuries were treated with surgical reduction and internal fixation at the time of fracture fixation.

showed that MR imaging is able to demonstrate most internal derangements of the knee efficiently (23). With arthroscopy used as the standard of reference, MR imaging was found to have greater than 85% accuracy in diagnosis of meniscal and ACL tears and a high negative predictive value (reliability of a negative MR imaging result) of 92.8%. The authors concluded that MR imaging is an effective diagnostic tool for ruling out internal derangement of the knee. In practice, arthroscopy is a more useful tool for managing meniscoligamentous injuries than for diagnosing them; therefore, preoperative assessment with MR imaging may be helpful. In addition, arthroscopy in the presence of a complex tibial plateau fracture is not without risk and can significantly increase surgical time.

Teaching Point

Because CT is an accepted and readily used examination for preoperative evaluation of bone injury, several authors have evaluated the ability of CT to demonstrate soft-tissue injury. Gardner et al (24) showed that the degree of depression and widening in type II fractures is predictive of soft-tissue injury. Depression of more than 6 mm or widening of more than 5 mm increased the likelihood of lateral meniscal injury (83% compared with 50% in fractures with less displacement). In addition, depression or widening of more than 8 mm was associated with an increased prevalence of medial meniscal injury. These findings suggest that depression or displacement at plain radiography or CT may be predictive of soft-tissue injury.

Teaching Point

CT may also be able to directly demonstrate ligamentous injuries (Figs 12, 13). Mui et al (25) used CT and MR imaging to evaluate 41 patients with tibial plateau fractures for evidence of ligament

Figure 13. Evaluation of PCL integrity in two patients with knee injuries. **(a, b)** Sagittal CT **(a)** and T2-weighted MR **(b)** images of a 34-year-old pedestrian who was struck by a motor vehicle while in a crosswalk (same patient as in Fig 12a and 12b) show a type IV tibial plateau fracture (incompletely seen). The PCL has a smooth contour on the CT image (arrow in **a**) and is partially torn on the MR image (arrow in **b**). **(c, d)** Sagittal CT **(c)** and T2-weighted MR **(d)** images of an 18-year-old patient show a dislocated knee, an injury that was sustained in a jump from a height. The PCL has a broad and irregular contour on the CT image (arrow in **c**) and is completely torn on the MR image (arrow in **d**). MR imaging also demonstrated tears of the fibulocollateral ligament, popliteus tendon, and medial and lateral menisci. These injuries were treated with a combined open and arthroscopic approach.

tear and avulsions. Smooth visible ligament contours without obscuration by increased attenuation in adjacent soft tissues suggested intact ligaments. CT demonstrated torn ligaments with 80% sensitivity and 98% specificity. Only 2% of ligaments deemed intact at careful CT evaluation had partial or complete tears at MR imaging.

CT angiography is largely replacing conventional angiography for evaluation of peripheral vessels and may be performed at the same time as CT for fracture evaluation. Arteriography should be considered when there is any alteration in the distal pulses or concern about arterial injury (9). Injuries sustained as a result of high-energy trauma or in association with compartment syndrome should also alert the surgeon to the need for arteriography.

Outcomes

In the vast majority of patients, an uneventful union is present at 1-year follow-up across all tibial plateau fracture types (17). Surgical findings can continue to improve for up to 2 years after definitive surgery, but secondary osteoarthritis may develop in as many as 31% of patients. Higher Schatzker classes are thought to be prognostic of poorer clinical outcomes, and studies have shown that unicondylar fractures have better functional results after treatment than do bicondylar fractures (17). However, this finding may not hold true for older patients, and patient age may have the most significant impact on functional outcome in treated fractures (11,26).

Across all age groups, among those fractures treated, satisfactory outcomes vary between 70% and 87% (2,11,27).

Conclusions

CT and MR imaging are more accurate than plain radiography for characterization and classification of tibial plateau fractures, and results of CT and MR imaging can be important for surgical planning. Currently, the clinical significance of preoperative diagnosis of meniscal and ligamentous injury is unknown; therefore, the choice of CT or MR imaging depends on what additional information the clinician needs.

References

1. Moore TM. Fracture-dislocation of the knee. Clin Orthop Relat Res 1981;156:128–140.
2. Schatzker J, McBroom R, Bruce D. The tibial plateau fracture: the Toronto experience, 1968–1975. Clin Orthop Relat Res 1979;138:94–104.
3. Schatzker J. Compression in the surgical treatment of fractures of the tibia. Clin Orthop Relat Res 1974;105:220–239.
4. Hohl M. Fractures of the proximal tibia. In: Rockwood CA, Green DP, Bucholz RW, eds. Fractures in adults. Philadelphia, Pa: Lippincott, 1991; 1725–1761.
5. Hohl M, Moore TM. Articular fractures of proximal tibia. In: Evarts CM, ed. Surgery of the musculoskeletal system. Vol 4, 2nd ed. New York, NY: Churchill Livingstone, 1990; 3471–3497.
6. Wicky S, Blaser PF, Blanc CH, Leyvraz PF, Schnyder P, Meuli RA. Comparison between standard radiography and spiral CT with 3D reconstruction in the evaluation, classification and management of tibial plateau fractures. Eur Radiol 2000;10(8): 1227–1232.
7. Yacoubian SV, Nevins RT, Sallis JG, Potter HG, Lorich DG. Impact of MRI on treatment plan and fracture classification of tibial plateau fractures. J Orthop Trauma 2002;16(9):632–637.
8. Macarini L, Murrone M, Marini S, Calbi R, Solarino M, Moretti B. Tibial plateau fractures: evaluation with multidetector-CT. Radiol Med 2004;108 (5-6):503–514.
9. Watson JT, Schatzker J. Tibial plateau fractures. In: Browner BD, ed. Skeletal trauma: basic science, management, and reconstruction. 3rd ed. Philadelphia, Pa: Saunders, 2003; 2047–2130.
10. Tscherne H, Lobenhoffer P. Tibial plateau fractures: management and expected results. Clin Orthop Relat Res 1993;292:87–100.
11. Su EP, Westrich GH, Rana AJ, Kapoor K, David HL. Operative treatment of tibial plateau fractures in patients older than 55 years. Clin Orthop Relat Res 2004;421:240–248.
12. Canale TS. Tibial plateau fracture. In: Canale ST, ed. Campbell's operative orthopaedics. 10th ed. Philadelphia, Pa: Mosby, 2006; 3146–3161.
13. Honkonen SE, Jarvinen MJ. Classification of fractures of the tibial condyles. J Bone Joint Surg Br 1992;74(6):840–847.
14. 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(2):97–119.
15. 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(8):1713–1721.
16. Bennett WF, Browner B. Tibial plateau fractures: a study of associated soft tissue injury. J Orthop Trauma 1994;8(3):183–188.
17. Rademakers MV. Operative treatment of 109 tibial plateau fractures: five- to 27-year follow-up results. J Orthop Trauma 2007;21(1):5–10.
18. Llinas A, McKellop HA, Marshall GJ, Sharpe F, Kirchen M, Sarmiento A. Healing and remodeling of articular incongruities in a rabbit fracture model. J Bone Joint Surg Am 1993;75(10):1508–1523.
19. Kode L, Lieberman JM, Motta AO, Wilber JH, Vasen A, Yagan R. Evaluation of tibial plateau fractures: efficacy of MR imaging compared with CT. AJR Am J Roentgenol 1994;163(1):141–147.
20. Friemert B, Oberlander Y, Schwarz W, et al. Diagnosis of chondral lesions of the knee joint: can MRI replace arthroscopy? A prospective study. Knee Surg Sports Traumatol Arthrosc 2004;12(1):58–64.
21. Solomon DH, Simel DL, Bates DW, Katz JN, Schaffer JL. Does this patient have a torn meniscus or ligament of the knee? Value of the physical examination. JAMA 2001;286(13):1610–1620.
22. Gardner MJ, Geller D, Suk M, 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(2):79–84.
23. Crawford R, Walley G, Bridgman S, Maffulli N. Magnetic resonance imaging versus arthroscopy in the diagnosis of knee pathology, concentrating on meniscal lesions and ACL tears: a systematic review. Br Med Bull 2007;84:5–23.
24. Gardner MJ, Yacoubian S, Geller D, et al. Prediction of soft-tissue injuries in Schatzker II tibial plateau fractures based on measurements of plain radiographs. J Trauma 2006;60(2):319–323; discussion 324.
25. Mui LW, Engelsohn E, Umans H. Comparison of CT and MRI in patients with tibial plateau fracture: can CT findings predict ligament tear or meniscal injury? Skeletal Radiol 2007;36(2):145–151.
26. Stevens DG, Beharry R, McKee MD, Waddell JP, Schemitsch EH. The long-term functional outcome of operatively treated tibial plateau fractures. J Orthop Trauma 2001;15(5):312–320.
27. Lachiewicz PF, Funcik T. Factors influencing the results of open reduction and internal fixation of tibial plateau fractures. Clin Orthop Relat Res 1990;259: 210–215.

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RadioGraphics

Schatzker Classification of Tibial Plateau Fractures: Use of CT and MR Imaging Improves Assessment

B. Keegan Markhardt, MD, et al

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Page 590
Management of type I, II, and III fractures centers on evaluating and repairing the articular cartilage.

Page 590
The fracture-dislocation mechanism of type IV fractures increases the likelihood of injury to the peroneal nerve or popliteal vessels (12).

Page 594
In Schatzker type V and VI fractures, the status of the soft tissues dictates management options.

Page 595
The authors concluded that MR imaging is an effective diagnostic tool for ruling out internal derangement of the knee.

Page 595
These findings suggest that depression or displacement at plain radiography or CT may be predictive of soft-tissue injury.