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Tibia Plateau Fractures: Etiology, Biomechanics, Complications, Evolution of Topography, Surgical Approaches, and Rehabilitation

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1. Mode, Mechanism of Injury, Anatomy, and Fracture Pattern

Tibia plateau fractures constitute an estimated 1 % of all fractures. Tibia plateau fractures are commonly seen in the elderly and young active population. The most common mode of injury overall is pedestrians struck by motorized vehicles (30%) followed by low energy falls (22%). The majority of tibial plateau fractures in the elderly are due to low energy falls, more so in females, and fractures involving the lateral tibial plateau are more common than medial condyle or bicondylar fractures. Whereas in the younger age group, high energy mechanisms predominate. Males are more susceptible among the younger and indicate an inversion of gender preponderance. Motor vehicular accidents, sports, and falls from height are among the leading causes of trauma (1) .

The medial plateau carries about 60% of the bodyweight (2) and consequently has, relative to the lateral plateau, a denser subchondral bone. Thus, medial plateau fractures usually result from a higher energy trauma as compared to lateral condylar ones. The lateral plateau is also higher than the medial plateau, accounting for a few degrees of varus of the tibial plateau about the tibia shaft. These structural differences, combined with the anatomical valgus axis of the knee joint and the natural tendency of the external impact laterally, make the lateral side more prone to fractures.

The description of the tibia plateau fracture injury mechanism in different publications had not been constant and so was the reliability. Schatzker classification (3) , which is based on antero posterior radiograph, is one of the most commonly used classifications, but it could not define injury mechanism in different knee positions. It was in 2016, that Wang et al (4) proposed the updated three - column concept system based on fracture configuration and injury mechanism. They used two points to determine the possible mechanism of injury: the position of the knee joint at the inciting event, concerning the relative position of the femur to the tibia (extension, flexion, hyperextension) as the initial position, and the direction of the culprit force (valgus, varus, axial). During knee flexion, femoral articular surface slides posteriorly on the tibial plateau surface, and as the axial load is being transmitted from the femoral to the tibial articular surface, a fracture might be caused on the posterior plateau. The posterior tibial slope angle (pTSA; Figure 1) (5) as measured on either the lateral radiographic plain film image or sagittal CT images, was used to represent the initial flexion/extension position at the time of impact. The initial position was considered as hyperextension when the pTSA is reversed (less than 0°, indicating recurvation), as extension when the PTSA ranges from 0° to 11°, or as flexion when it is more than 11°. Similarly, the disrupting force could be predicated on the inclination tendency of the tibia plateau in the coronal plane as well, using medial tibial plateau angle (mTPA, Figure 2) (6) , as measured on either anterior - posterior (AP) radiographic plain film image, or coronal CT images. Decreased mTPA indicated a primarily varus force, while an increased mTPA suggested mainly a valgus force. Fracture according to compression or tension failure mechanisms is also noted using the above radiographic parameters and fixation is applied accordingly. Using the two aforementioned radiographic parameters, Wang et explained that the lateral column fractures were caused primarily by valgus and axial forces in an extended knee. On the other hand, medial column fractures were caused by varus and axial forces with knee placed in extension at the time of trauma. Posterior coronal fracture indicated a shearing force, due to an axial load in a flexed knee. Similarly, medial and posterior column fractures are caused by an extension - varus mechanism as evident with reduced mPTA and pTSA. Lateral column fractures extending to the posterior column can be explained by extension - valgus or flexion - valgus injury mechanism. Increased pTSA indicated a flexion - valgus mechanism. Decreased pTSA and increased mTPA indicated an extension - valgus mechanism. Combined medial and lateral column fractures were caused by an axial force with the knee in extended position.

Low - energy trauma is a result of falls, especially in the elderly where articular depression is commonly seen. Type II Schatzker fractures are thus more common, as with aging, dense cancellous bone turns osteopenic. High energy mechanism is usually caused by direct trauma causing wedge or short oblique fractures with significant comminution, associated with soft tissue injury, compartment syndrome, and bone loss. So is the involvement of neurovascular structures, namely common peroneal nerve palsy and popliteal vessel injury.

Complications

Being a periarticular fracture, certain complications are inherent to the traumatic insult caused to the articular cartilage and soft tissues around. Broadly complications associated with tibial plateau fracture are divided into injury - related and surgical complications, atvarious time frames.

Injury - Related

Immediate

Given the paucity of soft tissues in the vicinity of the knee, tibia plateau fractures carry a high risk of injury to the soft tissue envelope. The severity of soft tissue injury reflects the energy transmitted to the bone and predisposes to acute compartment syndrome. In general, the incidence of ranges from 0.7% to 12%. However, the incidence of compartment syndrome and fasciotomy can be upto 53%in Schatzker type IV - VI fractures (7) .

Another potentially devastating complication seen with high - energy tibia plateau fractures is the compromise of neurovascular structures in the vicinity of knee. Vascular injuries are commonly seen in high - velocity tibial plateau fractures, especially those involving medial plateau. A single - center retrospective review of 178 consecutive patients revealed that incidence of vascular injury in tibia plateau fractures is 2% (8) . In contrast, little data is reported about the incidence of associated neurological deficit. Overall, there's 1% incidence of peroneal nerve palsy in tibia plateau fractures (9) and, is commonly associated with varus mechanism with posterolateral corner injuries (10) .

Intervention Related

Short - term (wound complications, infection, deep vein thrombosis), mid - term (mal - union, non - union), or late (post - traumatic arthritis). Complications are many and can be divided into Most early complications are biological failures, while late failures are often caused by mechanical issues.

Early Postoperative Complication

Soft tissues (wound dehiscence, skin necrosis) and septic (wound infection) complications have been historically recognized as the most frequent ones after surgical treatment of high - energy proximal tibia fractures. The reported incidence of these complications in the literature reaches up to 50–80% of cases. Overall, up to 5.63 % need delayed primary closure, and 4.22% require skin grafting. A retrospective analysis of 987 patients by Junyong Li (11) revealed that overall incidence of deep vein thrombosis (DVT) following tibial plateau fracture was 4.7%, out of which 1.0% accounted for proximal and 3.7% for the distal DVT, with a positive correlation of post - surgical DVT to a hospitalization period of more than 11 days. The same study concluded that there were 5 independent factors associated with post - operative DVT - age ($\geq$ 41 vs < 41 years), general anesthesia, hyponatremia, prolonged operative time, and increased serum D - dimer. Wang et al (12) reported DVT rate of up to 45.4% in 176 tibial plateau fractures, despite all the patients receiving low molecular weight heparin (LMWH) thromboprophylaxis and pneumatic compression both before and after surgery.

Also, these injuries hamper an individual's economic prosperity. For patients whose jobs require a high degree of locomotion, these injuries may cause a remarkable delayed return to employment (13) .

Mid - Term Complications

Malunion

Malunion is one of the complications relating to fracture healing. It is associated with late articular collapse or deformation of the metaphysis - shaft junction as a consequent suboptimal recognition and fixation of fracture (14) . Rademakers et al (15) followed 202 tibial plateau fracture patients for 1 year and found that around 4% patients had malunion. Meulenkemp et al (16) in their prospective cohort study of 65 patients, reported varying distribution of the mal - reduction in different segments of the tibial plateau when assessed via post - operative CT scan.32.3% post - surgical CT scans had mal - reduction with only 23% of them involving the anterolateral quadrant in sharp contrast to 77% of mal - reductions in the posteromedial quadrant (16) . In the pre - CT era failure to identify and tackle the shear fracture has been the commonest cause of fracture malunion leading to posterior inferior dislocation, severe various alignment, and poor clinico - radiological results.

Non - union

Non - union after tibial plateau fracture isa relatively rarely reported complication after tibial plateau fracture. Causes include - infection, high grade comminution, instability of fixation or mechanical failure, absence of bone grafting in void, or amalgamation of these. Rademakers et al (15) reported 1% non - unions, both caused by surgical site infection. Urrela et al reported 2 non - unions after treatment of 96 Schatzker I - IV fractures, one due to infection while the other was caused by fixation failure. Manidakis et al (17) in their study of 101 tibia plateau fractures, reported a non - union rate of 2%. In contrast, Ruffolo et al found a 10% incidence of non - union among 140 bicondylar fractures treated with ORIF, with only 6 cases having a non - infective etiology.

Late Complications

Post - traumatic osteoarthritis (PTOA)

Several factors have been shown to influence poor outcomes, which include severity of injury, articular incongruity or malalignment, associated soft tissue injury, and age at the time of injury. Most IAFs occur in patients younger than 45, and patients who develop PTOA are on average 9 to 14 years younger than those with osteoarthritis (OA). This makes the treatment of PTOA difficult, as patients are often younger, more active, and have higher functional demands than those with OA. The incidence of PTOA after tibia plateau Fractures is between 10% and 58%, and in 7.3% total knee arthroplasty was ultimately required (17–19) . In patients, with an average age between 42 and 57 years, quite a few studies reported radiologic evidence of osteoarthritis in 20–37%, 3–7 years post - surgery (3, 20, 21) . In older patients, Su et al reported similar degenerative changes in 60% of patients, of which, however, only 8% underwent a joint arthroplasty (22) . These patients are at 5 times higher risk of undergoing a total knee arthroplasty in a matched cohort (Wasserstein 2014) which depends on the patient's age and the complexity of the fracture. However, over 10 years, only 7.3% tibia plateau patients need a TKA as compared to 2% patients in absence of fracture. As against a primary OA, TKA in PTOA is technically challenging because of previous surgical scar (Lunebourg 2014) and implants in situ. Varus/valgus constrained, hinged and PCL constrained prostheses are commonly used implants in such cases (Softness 2017). However, existing literature is controversial in terms of clinical outcomes after TKA in PTOA. Lizaur - Utrilla et al, in their prospective matched cohort, no significant difference in KSS score between TKA in primary OA (n=29) & PTOA (n=58) in the two groups at follow - up of at least till 5 years postoperatively. In contrast, Bala et al in their retrospective analysisreported rate of some complications as higher in these cases (n=3509) as compared to those in primary TKA. Post - operative complications in the PTOA group (n= 257, 611) were found to be statisticallysignificant at 90 - days, 2 - year and 5 - year follow up for arthrotomy/incision & drainage (I&D), cellulitis or seroma, closed fracture, periprosthetic infection, (Total knee arthroplasty) TKA revision, and wound complications. However, broken prosthetic joints, dislocation of the prosthetic joint, mechanical complications, patellar complications, periprosthetic fracture, and extensor mechanism rupture did not reach statistical significance at 5 - year follow - up. Overall, incidence of peri - prosthetic fracture, peri - prosthetic infection & TKA revision were 0.66%, 4.93% & 4.87% respectively, in the PTOA. Similarly, Scott et al reported the incidence of wound complications and stiffness reaching statistical significance, higher in the PTOA cohortthan in the OA cohort, over a 5 - year follow - up.

A miscellaneous group of complications of tibial plateau fractures include an inability to regain normal gait, osteoarthritis of the knee, ankle osteoarthritis secondary to an abnormal gait, and chronic pain; these problems may affect the activities of daily living (23–25) .

2. Evolution of Management

Fracture understanding

In the 1950s, 60s, and 70s the predominant treatment modality was conservative, and published results indicated favorable outcomes using a variety of techniques including traction, and cast bracing (Apley controlled deformity using longitudinal traction & encouraged early knee motion), and even spica casting (26) . Later in the 1980s, favorable results were also reported with improved techniques of internal fixation, operatively reducing and fixing tibia plateau fractures.

Marchant first described tibia plateau fractures (27) In 1960, Duparc and Ficat published one of the most complete classifications which were further simplified in 1990 (28) . The Schatzker classification (3) and OTA/AO (29) classification remain the key practical and most internationally accepted classification systems. The OTA/AO distinguishes ranges of severity in high - energy patterns, seems better in describing medial plateau fractures, and is more reliable than the Schatzker classification (30) . But the one by Schatzker defines patho - anatomy, considers bone quality, age, explains mechanism, and suggests treatment strategies and therefore, remains popular. Neitherincludes fracture - dislocation patterns which are seen in high energy trauma and do not specifically evaluate the posterior tibia plateau fractures (which comprise 65% of all proximal tibia fractures) (31) .

To overcome these shortcomings, in 2010, Luo et al (32) and Chang et al (33) in 2014 emphasized the importance of computed tomography (CT) scan in surgical planning of tibial plateau fracture and gave the column concept and quadrant for fracture - specific and fragment - specific planning. This concept of fracture - specific planning widened the need for surgical exposure besides the commonly used antero - lateral (34) and the postero - medial (which may be combined with the antero - lateral (35) one) approaches. With the frequent use of the CT scan for surgical planning importance of the fracture location was recognized. For better and very precise fracture localization Krause (36) devised Eight/Ten segment classification in 2016 which was then followed by a Four column - Nine segment classification by Yao (37) to elucidate the morphology of various fracture configurations. But all these new classifications increased the complexity of the fracture localization without any further information about the mechanism of the injury and fracture planning. Wang et al (4) then proposed the ‘‘updated Three - Column Concept’’ (u - TCC), and added the fracture displacement pattern to identify the mechanism of injury and surgical planning. Based on the concept prospectively reported improves clinical and radiological outcomes with their fixation strategy.

Despite wide acceptance of the u - TCC the morphological description of the fracture still lags and Schatzker classification remains the commonly accepted method for morphological description of the tibial plateau fracture, which is often limited to give CT - based morphological details. Kfuri (38) in 2018 revisited the Schatzker classification and added the three - dimensional element of computed tomography to localize the exact spatial location of the major fracture dimensions and understand injury mechanism as well as to determine precisely the surgical approach and fixation mode.

Surgical approaches

The anterolateral quadrant is most commonly involved and thus the standard anterolateral approach is most commonly used, where a straight incision is used and the landmarks being lateral femoral epicondyle and Gerdy’s tubercle (39) . An anteromedial fragment warrants a medial approach; medial femoral epicondyle and medial border of tibial crest form the landmarks (40) .

Given increased columns of the tibial plateau, more surgical approaches evolved in order to address all possible fracture segments. Major evolution happened in the surgical approaches to address the posterior column. The posteromedial approach is commonly used when there's a medial plateau or a bicondylar fracture (41) . With this approach, plate fixation can be done on the medial or posteromedial aspect.

The posterior approaches are also commonly employed, especially when a posteromedial shearing fracture is involved. First described in 1997 (42) , it has undergone different modifications (43, 44) . This approach also allows limited access to the posterolateral tibia plateau for an oblique buttress plate placement.

The posterolateral aspect remains largely inaccessible through the usual approaches and entails a separate surgical exposure. The initial posterolateral approaches included fibular osteotomy but at the risk of relatively extensive trauma to posterolateral corner structures. Frosch et al (45) devised a posterolateral approach without fibular osteotomy which in turn, limited visualization. This was modified later to provide direct surgical exposure to the posterolateral part of tibia plateau without damaging the important soft tissue and ligamentous structures. In addition, a safe and simple arthrotomy allowed for a reduced operative time. However, risk of potential injury to the inferolateral geniculate, anterior tibial arteries as well as the common peroneal nerve, remained a concern.

However, there was an unmet need for an ideal surgical approach that can expose entire posterior tibial plateau, inclusive of both posteromedial and posterolateral corners for better fracture manipulation and implant positioning (46) , with due consideration to prevent neurovascular injury and devascularisation of the cortical window. All these concerns were addressed by the posterior midline gastrocnemius raphe split approach (47) . It was a modification of posterior midline approach for PCL fixation. In the prone position, blunt dissection of gastrocnemius allows for lateral retraction of its lateral head and accompanying neurovascular bundle safely. Ligature of medial inferior genicular artery at the superior border of popliteus eases the lateral retraction of the neurovascular bundle, circumventing concern of neurovascular injury. This approach also could be combined with other approaches where due attention is to be given to anteromedial and anterolateral quadrants or even associated ligament injury, allowing single - stage management without compromising the outcome (48) .

Rehabilitation

All above mentioned advances in the understanding of the fracture morphology, surgical planning with column concept, modified surgical approach for fracture specific fixation and anatomical locking plate made the osteosynthesis stable enough to allow early and aggressive rehabilitation of these complex knee injuries (49–51) . Currently, there are two different weight - bearing regimens, Permissive weight - bearing protocol (PWB) and Restrictive weight - bearing protocol (RWB) used during the rehabilitation.

RWB protocol was advocated by AO, which included a period of non - weight bearing for 10 - 12 weeks. This was often found to have a concern about patient compliance (52) . The rationale for the delayed weight - bearing was due to fear of loss of fracture reduction, which is associated with even worse outcomes - secondary osteoarthritis and proportional increase in risk of post - traumatic arthritis.

However, as far as loss of fracture reduction is concerned with respect to early weight - bearing, recent evidence proves otherwise. Segal et al (53) reported on 44 patients who were treated operatively and no loss of articular reduction greater than 2 mm was found, in any of the patients. Haak et al (54) reported on 12 patients who were allowed to bear weight immediately. There was no radiographic displacement. Eggli et al (55) permitted 10Kg of weight - bearing in 14 patients with high energy fracture patterns who were treated with dual plating. None of the patients experienced loss of fixation or loss of reduction.

Elderly patients are either unwilling or unable to maintain weight - bearing restrictions (52) , besides that deep vein thrombosis could be a catastrophic complication (56) . On the contrary, the early weight - bearing protocol gives a psychological advantage to the trauma victim and benefits such as it may limit complications including knee joint stiffness, muscle and bone atrophy, synovial adhesions and capsular contractions (57) , faster fracture union, reduced biomechanical energy expenditure during ambulation, decreased risk of venous thromboembolism, benefits such as earlier return to work, due to shorter period of hospital stay (58) .

While Protocols for postoperative weight - bearing of these fractures were formulated more than 60 years ago, and advocate delayed weight - bearing, there is still an absence of a worldwide consensus among surgeons about permissive weight - bearing (59) versus restrictive weight - bearing. As per the current clinical practice, a wide majority of surgeons do not follow delayed weight - bearing protocol in their post - operative rehabilitation regimen (60) .

3. Summary

The past few decades have witnessed advances in imaging modalities, surgical concepts, planning, and biomechanically better implants, and so is the shift in the post - operative rehabilitation protocols, from late to early - weight bearing. However, the post - operative weight - bearing regimen needs to be standardized.

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Conflict of Interest

The authors declare that they have no competing interests.

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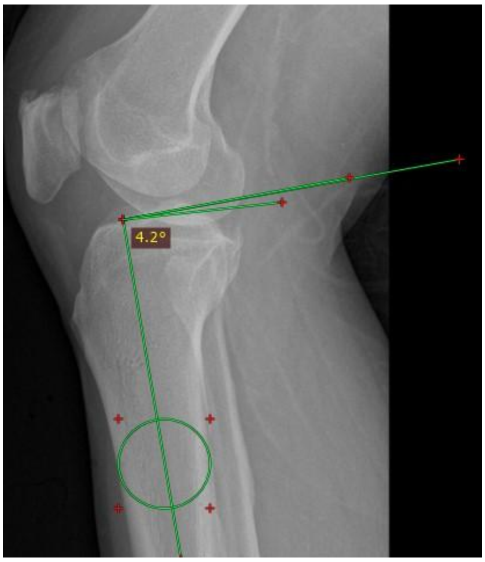

Figure 1: In lateral view (X - ray film), diaphyseal axis of tibia is taken as midpoint of anterior and posterior cortices of proximal tibia. The angle so formed between a line along the lateral plateau and perpendicular to the diaphyseal is the pTSA.

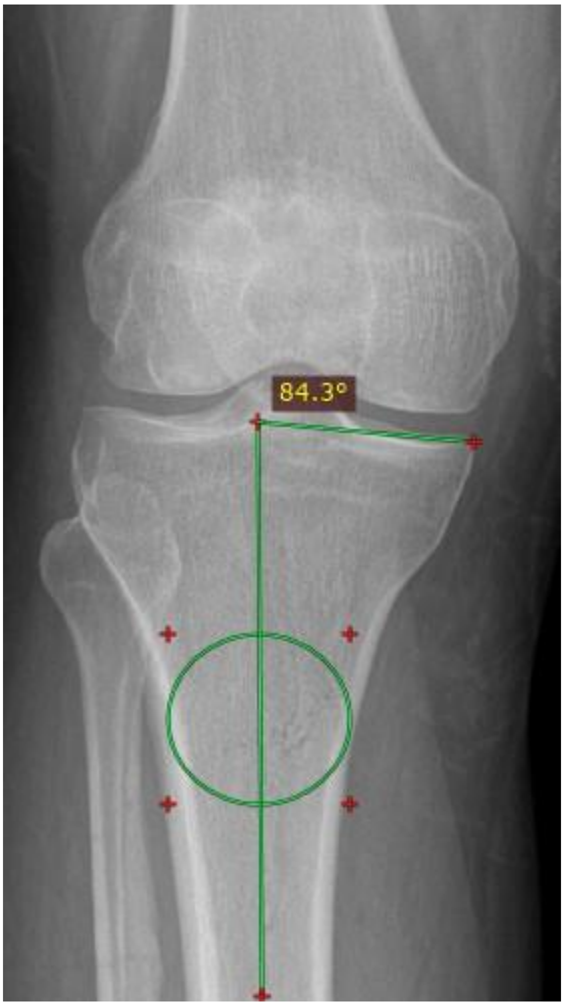

Figure 2: In anteroposterior view (X - ray film), diaphyseal axis of tibia is taken as midpoint of medial and lateral cortices of proximal tibia. The angle so formed between this axis and a line parallel to medial tibia plateau is the mPTA.