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Correlation Between Radiographic Parameters and Ligamentous-Meniscal Injuries in Tibial Plateau Fractures: A Prospective Observational Study

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Tibial plateau fracture; Ligament injury; Meniscal injury; Lateral plateau depression; Lateral plateau widening; MRI; CT scan.

ABSTRACT

Background: Tibial plateau fractures are frequently associated with ligamentous and meniscal injuries that can significantly impact treatment decisions and functional outcomes. This study aimed to evaluate the correlation between radiographic parameters, specifically lateral plateau depression (LPD) and lateral plateau widening (LPW), and the presence of ligamentous and meniscal injuries.

Methods: A prospective observational study was conducted on 24 patients with proximal tibial plateau fractures. Plain radiographs, CT scans, and MRI were performed for all patients. LPD and LPW were measured on both plain radiographs and CT scans. Fractures were classified according to the Schatzker system. Associated ligamentous and meniscal injuries were documented based on MRI findings.

Results: The most common soft tissue injury was lateral meniscus tear (41.6%), followed by ACL injury (37.5%), LCL injury (20.8%), PCL injury (20.8%), MCL injury (16.6%), and medial meniscus injury (8.3%). Ligamentous and meniscal injuries occurred at minimum values of LPD (3.2 mm) and LPW (2 mm) on both plain radiographs and CT scans. High-velocity injuries (67%) were associated with a significantly higher incidence of ligamentous and meniscal injuries compared to low-velocity injuries (p=0.04). Statistical analysis revealed a significant correlation between CT parameters (LPD and LPW) and MRI findings of ligamentous and meniscal injuries (p≤0.05).

Conclusion: CT parameters can reliably predict ligamentous injuries in tibial plateau fractures, which is valuable when MRI is not immediately available. Lateral plateau widening was found to be superior to articular depression in predicting meniscal and ligamentous injuries. Early recognition and appropriate management of these associated soft tissue injuries are crucial for optimizing outcomes in tibial plateau fractures.

INTRODUCTION:

Tibial plateau fractures represent complex injuries of the articular and metaphyseal segments that significantly impact knee joint function. These fractures account for approximately 1% of all fractures and primarily affect adults between 40 and 60 years of age.[1,2] The complex nature of these injuries extends beyond bony involvement to include associated soft tissue injuries, particularly ligamentous and meniscal structures, which substantially influence functional outcomes and treatment strategies.[3] The incidence of concomitant soft tissue injuries in tibial plateau fractures has been reported to range from 56% to 99%, highlighting their clinical significance.[4,5]

The mechanism of injury typically involves a combination of axial loading with varus or valgus forces, resulting in compression and/or splitting of the articular surface.[6] These loading patterns lead to both fracture patterns and associated soft tissue disruption. High-energy mechanisms typically produce more complex fracture patterns and have higher rates of associated ligamentous and meniscal injuries.[7] In contrast to isolated ligamentous injuries where clinical examination can often establish diagnosis, the presence of fracture, pain, and hemarthrosis in tibial plateau fractures renders clinical evaluation of ligamentous integrity challenging, necessitating advanced imaging modalities.[8]

The Schatzker classification system, widely used to categorize tibial plateau fractures, provides valuable information about fracture morphology but does not account for associated soft tissue injuries.[9] Studies have demonstrated an increased incidence of ligament tears with higher Schatzker grades, particularly in types IV through VI, which represent higher energy injuries.[10] However, even lower-energy fracture patterns may have significant associated soft tissue damage that can be overlooked without appropriate evaluation.[11]

Proper diagnosis of these concomitant soft tissue injuries is crucial, as unrecognized and untreated ligamentous or meniscal damage can lead to chronic instability, accelerated post-traumatic arthritis, and poor functional outcomes.[12,13] While the effect of primary repair of concomitant ligament injuries remains debated, identifying and addressing these injuries during surgical planning can significantly influence postoperative rehabilitation protocols and overall outcomes.[14]

Traditional radiographic evaluation with plain radiographs provides limited information regarding soft tissue injuries. Parameters such as lateral plateau depression (LPD) and lateral plateau widening (LPW) have been proposed as potential radiographic predictors of associated soft tissue injuries.[15,16] Some studies suggest that when depression and widening displacement exceed approximately 5mm on radiographs, the incidence of lateral meniscus, lateral collateral ligament, and posterior cruciate ligament injuries increases significantly.[17]

Advanced imaging modalities, particularly Magnetic Resonance Imaging (MRI) and Computed Tomography (CT), have revolutionized the preoperative evaluation of tibial plateau fractures. MRI provides excellent visualization of soft tissue structures and can accurately identify meniscal and ligamentous injuries, while CT offers superior bony detail for fracture characterization.[18,19] However, MRI is not universally available in all centers, particularly in emergency settings, and incurs additional costs and time delays in management.[20]

Given these constraints, identifying reliable radiographic and CT-based parameters that can predict associated soft tissue injuries becomes clinically relevant. Several studies have attempted to correlate radiographic measurements with the incidence of soft tissue injuries, but results have been variable, and consensus guidelines are lacking.[21,22] Developing predictive models based on readily available imaging could help surgeons anticipate and plan for associated soft tissue injuries even when MRI is unavailable or impractical.

Our study aims to evaluate the correlation between radiographic and CT measurements (particularly LPD and LPW) and associated ligamentous and meniscal injuries confirmed by MRI in patients with tibial plateau fractures. By establishing reliable imaging predictors, we hope to enhance preoperative planning and improve surgical decision-making in the management of these complex injuries.

MATERIALS AND METHODS:

Study Design and Population:

This prospective observational study was conducted at the Department of Orthopaedics, Kamineni Institute of Medical Sciences, Narketpally, Telangana, India, from August 2022 to May 2024 after obtaining approval from the Institutional Ethics Committee (Ref. No. ETHICS COMMITTEE/KIMS/NKP/Aug 2022/15). A total of 24 patients with traumatic proximal tibia fractures were included in the study after applying inclusion and exclusion criteria.

The inclusion criteria were: (1) patients aged between 18 and 60 years of both genders with traumatic proximal tibia fractures requiring surgical intervention; (2) patients willing to participate in the study; and (3) patients with adequate imaging studies including plain radiographs, CT scans, and MRI. The exclusion criteria were: (1) patients younger than 18 years or older than 60 years; (2) known patients of any musculoskeletal or joint disorders; (3) proximal tibia fractures with ipsilateral fractures of femur; (4) segmental fractures of tibia; and (5) patients who declined to participate in the study.

Written informed consent was obtained from all patients after explaining the purpose and nature of the study in their native language. Demographic data including age, gender, occupation, mechanism of injury, and fracture characteristics were recorded for all patients.

Clinical Assessment:
A thorough history was taken from each patient, including the mechanism of injury, which was categorized as high-energy (road traffic accidents, falls from height >1 meter) or low-energy trauma (simple falls, sports injuries).[23] Complete physical examination was performed, including assessment of the knee for hemarthrosis, neurovascular status, and compartment evaluation of the leg. As noted by previous investigators, clinical evaluation of knee instability was not performed in the acute setting due to pain and discomfort.[24,25]

Radiological Evaluation:
Plain Radiography:
Standard anteroposterior (AP) and lateral radiographs of the affected knee were obtained for all patients. The extent of lateral plateau depression (LPD) and lateral plateau widening (LPW) was measured on AP radiographs using the methods described by Gardner et al.[26] The LPD was calculated in millimeters by measuring the difference between a reference line drawn from the extension of the medial plateau of tibia parallel to the joint line (b) and a line parallel to the reference line drawn from the maximum lateral plateau depression (b'). The LPW was calculated in millimeters between a tangential line to the lateral femoral epicondyle (a') which is perpendicular to (b) and a line drawn from the most lateral part of the lateral tibial plateau (a) which is parallel to (a').

Computed Tomography (CT):
All patients underwent multidetector computed tomography (16-slice MDCT) of the affected knee. The coronal images were used to measure the LPD and LPW using the same method described for plain radiographs.[27,28] The measurements on CT scans were performed independently by a musculoskeletal radiologist who was blinded to the radiographic measurements and MRI findings.

Magnetic Resonance Imaging (MRI):
MRI of the affected knee was performed using a 1.5 Tesla MRI scanner (Siemens Magnetom Avanto) with a dedicated knee coil. After removing any external splint, patients were positioned supine with the knee in a neutral position. The standardized protocol included: (1) coronal and sagittal T1-weighted images (T1WI); (2) coronal, sagittal, and axial proton density-weighted images with fat suppression (PDFS); (3) coronal and sagittal T2-weighted images with fat suppression (T2FS); and (4) axial T2-weighted images.[29,30]

MRI images were reviewed by a musculoskeletal radiologist with 10 years of experience who was blinded to the radiographic and CT measurements. The following structures were systematically evaluated: (1) anterior cruciate ligament (ACL); (2) posterior cruciate ligament (PCL); (3) medial collateral ligament (MCL); (4) lateral collateral ligament (LCL); (5) medial meniscus (MM); and (6) lateral meniscus (LM). The ligamentous injuries were graded as: Grade I (sprain with intact fibers), Grade II (partial tear), and Grade III (complete tear).[31] Meniscal injuries were documented based on their location (anterior horn, body, posterior horn) and pattern (horizontal, vertical, radial, complex, or root tear).[32]

Fracture Classification:
Tibial plateau fractures were classified according to the Schatzker classification system based on the radiographic and CT findings.[33] The classification was performed independently by two senior orthopedic surgeons, and any discrepancies were resolved by consensus.

Statistical Analysis:
Data analysis was performed using SPSS software version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for demographic data and fracture characteristics. Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages.

The association between radiographic parameters (LPD and LPW) measured on plain radiographs and CT scans and the presence of ligamentous and meniscal injuries detected on MRI was analyzed using logistic regression analysis. The minimum threshold values of LPD and LPW at which specific ligamentous and meniscal injuries occurred were determined. Receiver operating characteristic (ROC) curves were generated to determine the sensitivity and specificity of these threshold values.

The correlation between radiographic measurements (LPD and LPW) and MRI findings was analyzed using Spearman's correlation coefficient. The interobserver reliability for fracture classification was assessed using Cohen's kappa coefficient. A p-value of ≤ 0.05 was considered statistically significant.

Ethical Considerations:
The study was conducted in accordance with the

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ethical principles outlined in the Declaration of Helsinki. Patient confidentiality was maintained throughout the study, and all patient-identifying information was anonymized during data collection and analysis. The study protocol was reviewed and approved by the Institutional Ethics Committee of Kamineni Institute of Medical Sciences (Ref. No. ETHICS COMMITTEE/KIMS/NKP/Aug 2022/15).

RESULTS

Demographic and Clinical Characteristics

A total of 24 patients with proximal tibial plateau fractures who met the inclusion criteria were enrolled in this study. The demographic and clinical characteristics of the study population are summarized in Table 1. The mean age of the patients was 46.71 ± 9.21 years (range, 27-60 years), with the majority (70%) in the 40-60 years age group. Males comprised 75% (n=18) of the study population, while females accounted for 25% (n=6).

Table 1: Demographic and Clinical Characteristics of the Study Population (N=24)

Characteristic	Number (%) or Mean ± SD
Age (years)	46.71 ± 9.21
20-40 years	7 (30%)
40-60 years	17 (70%)
Gender	
Male	18 (75%)
Female	6 (25%)
Side involved	
Left	14 (58.4%)
Right	10 (41.6%)
Mechanism of injury	
Road traffic accident	17 (70.8%)
Fall from height	2 (8.3%)
Slip and fall	2 (8.3%)
Others	3 (12.6%)
Velocity of injury	
High	16 (67%)
Low	8 (33%)

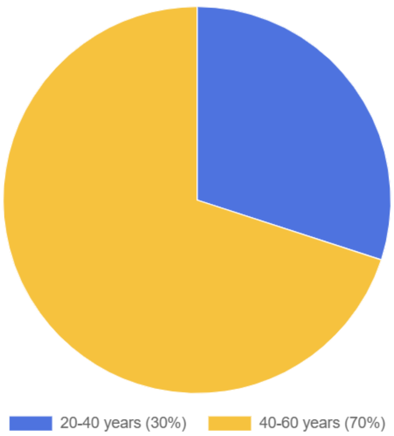

Fig 1: Pie chart showing age distribution of tibial plateau fractures

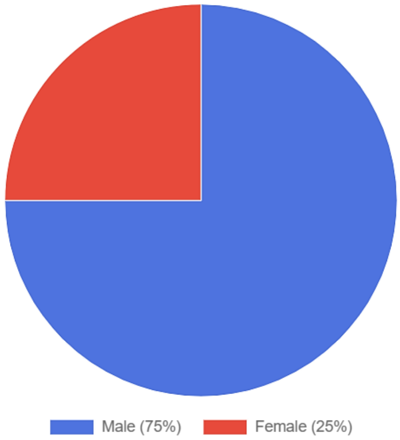

Fig 2: Pie chart showing gender distribution of tibial plateau fractures

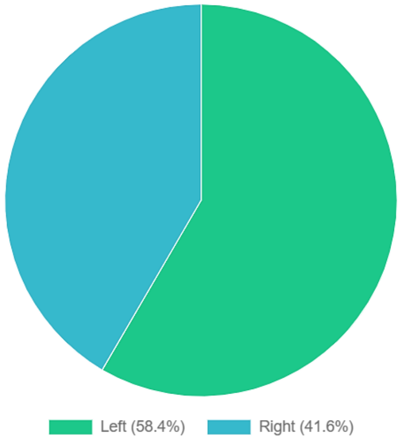

Fig 3: Pie chart showing side distribution of tibial plateau fractures

The left knee was involved in 58.4% (n=14) of cases, while the right knee was affected in 41.6% (n=10) of cases. Road traffic accidents were the most common mechanism of injury, accounting for 70.8% (n=17) of cases, followed by falls from height and slip and fall injuries at 8.3% (n=2) each, and other mechanisms in 12.6% (n=3) of cases. The majority of injuries (67%, n=16) were high-velocity trauma, while 33% (n=8) were low-velocity injuries.

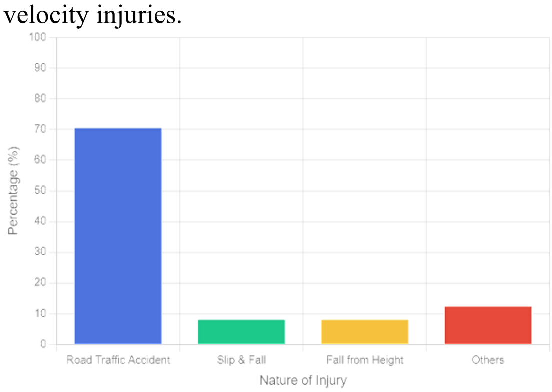

Fig 4: Bar graph showing percentage of tibial plateau fractures with different nature of injury

Fracture Classification and Soft Tissue Injuries
The distribution of fractures according to the Schatzker classification and associated ligamentous and meniscal injuries is presented in Table 2. The most common fracture pattern was Schatzker type V (29.2%, n=7), followed by types I and II (25% each, n=6), type IV (16.7%, n=4), and type III (4.1%, n=1). No type VI fractures were observed in our study population.

Table 2: Distribution of Ligamentous and Meniscal Injuries According to Schatzker Classification

Schatzker Classification	Number (%)	LM	MM	ACL	PCL	MCL	LCL
Type I (n=5)	5 (20.8 %)	3	0	2	0	0	1
Type II (n=6)	6 (25%)	3	1	1	0	0	0
Type III (n=1)	1 (4.2%)	0	0	1	0	0	0
Type IV (n=5)	5 (20.8 %)	2	0	3	2	1	1
Type V (n=7)	7 (29.2 %)	2	1	2	3	3	3
Total	24 (100 %)	10	2	9	5	4	5

LM: Lateral Meniscus, MM: Medial Meniscus, ACL: Anterior Cruciate Ligament, PCL: Posterior Cruciate Ligament, MCL: Medial Collateral Ligament, LCL: Lateral Collateral Ligament

Overall, 19 patients (79.2%) had at least one ligamentous or meniscal injury detected on MRI. The most common soft tissue injury was lateral meniscus tear (41.6%, n=10), followed by ACL injury (37.5%, n=9), LCL injury (20.8%, n=5), PCL injury (20.8%, n=5), MCL injury (16.6%, n=4), and medial meniscus injury (8.3%, n=2).

Table 3: Overall Incidence of Ligamentous and Meniscal Injuries

Structure	Number (%)
Lateral Meniscus (LM)	10 (41.6%)
Medial Meniscus (MM)	2 (8.3%)
Anterior Cruciate Ligament (ACL)	9 (37.5%)
Posterior Cruciate Ligament (PCL)	5 (20.8%)
Medial Collateral Ligament (MCL)	4 (16.6%)
Lateral Collateral Ligament (LCL)	5 (20.8%)

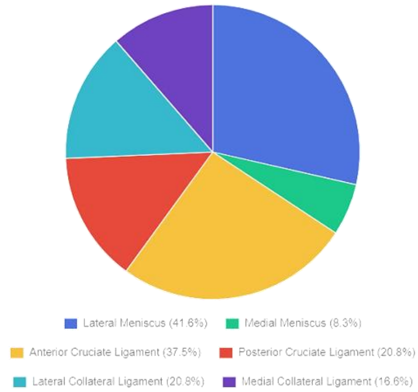

Fig 6: Pie chart showing distribution of total ligamentous & meniscal injuries in the study

The relationship between velocity of injury and associated soft tissue injuries was analyzed. High-velocity injuries were associated with a significantly higher incidence of ligamentous and meniscal injuries compared to low-velocity injuries (p=0.04).

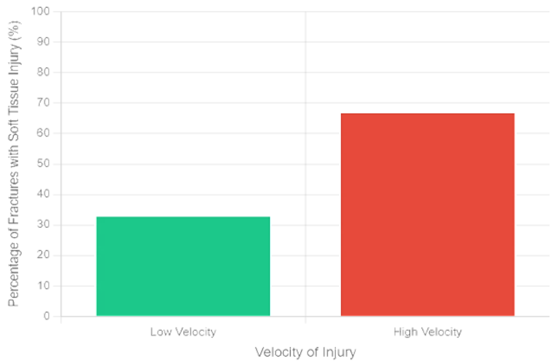

Fig 5: Bar graph showing relationship between velocity of injury and fracture with ligament & meniscal injury

Radiographic and CT Parameters as Predictors of Soft Tissue Injuries:
Lateral Plateau Depression (LPD):
The minimum threshold values of LPD on plain radiographs at which specific ligamentous and meniscal injuries occurred are presented in Table 4. The mean LPD on plain radiographs was 6.93 ± 4.07 mm (range, 0-14 mm), while the mean LPD on CT scans was 6.76 ± 2.98 mm (range, 1.1-11.9 mm).

Table 4: Minimum Lateral Plateau Depression (LPD) Values on Plain Radiographs at Which Various Ligament Injuries Occurred

Ligament & Meniscal Injury	Minimum LPD (mm)
Lateral Meniscus (LM)	4.5
Medial Meniscus (MM)	8.2
Anterior Cruciate Ligament (ACL)	4.5
Posterior Cruciate Ligament (PCL)	7.5
Lateral Collateral Ligament (LCL)	3.2
Medial Collateral Ligament	3.2

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(MCL)	

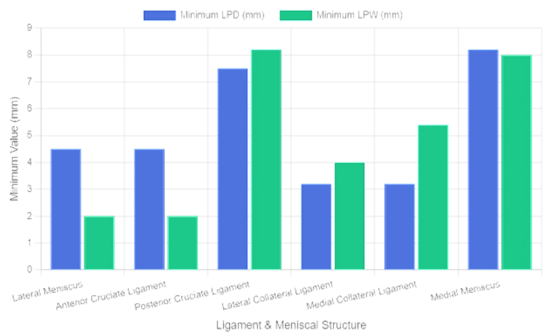

Fig 7: Bar graph showing threshold of LPD (mm) in X-ray for ligament & meniscal injuries

Table 5: Minimum Lateral Plateau Depression (LPD) Values on CT Scans at Which Various Ligament Injuries Occurred

Ligament & Meniscal Injury	Minimum LPD (mm)
Lateral Meniscus (LM)	3.2
Medial Meniscus (MM)	10
Anterior Cruciate Ligament (ACL)	4.5
Posterior Cruciate Ligament (PCL)	7.5
Lateral Collateral Ligament (LCL)	3.2
Medial Collateral Ligament (MCL)	3.2

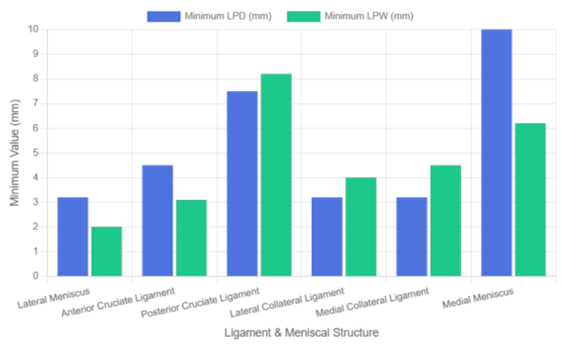

Fig 8: Bar graph showing threshold of LPD (mm) in CT for ligament & meniscal injuries

Lateral Plateau Widening (LPW):

The mean LPW on plain radiographs was 5.90 ± 4.66 mm (range, 0.9-22.5 mm), while the mean LPW on CT scans was 7.17 ± 4.56 mm (range, 1.2-19 mm). The minimum threshold values of LPW on plain radiographs and CT scans at which specific ligamentous and meniscal injuries occurred are presented in Tables 6 and 7, respectively.

Table 6: Minimum Lateral Plateau Widening (LPW) Values on Plain Radiographs at Which Various Ligament Injuries Occurred

Ligament & Meniscal Injury	Minimum LPW (mm)
Lateral Meniscus (LM)	2
Medial Meniscus (MM)	8
Anterior Cruciate Ligament (ACL)	2
Posterior Cruciate Ligament (PCL)	8.2
Lateral Collateral Ligament (LCL)	4
Medial Collateral Ligament	5.4
(MCL)	

Table 7: Minimum Lateral Plateau Widening (LPW) Values on CT Scans at Which Various Ligament Injuries Occurred

Ligament & Meniscal Injury	Minimum LPW (mm)
Lateral Meniscus (LM)	2
Medial Meniscus (MM)	6.2
Anterior Cruciate Ligament (ACL)	3.1
Posterior Cruciate Ligament (PCL)	8.2
Lateral Collateral Ligament (LCL)	4
Medial Collateral Ligament (MCL)	4.5

Correlation of Radiographic and CT Parameters with MRI Findings:

The correlation between radiographic and CT parameters (LPD and LPW) and MRI findings of ligamentous and meniscal injuries is summarized in Table 8.

Table 8: Correlation of LPD & LPW as Predictors of Ligament & Meniscal Injury from X-ray, CT, and MRI

MRI Findings	LPD X-ray (mm)	LPD CT (mm)	LPW X-ray (mm)	LPW CT (mm)	%
LM	4.5-10.8	3.2-8	2-14.4	3.1-18	41.6
MM	8.2-14	10-11.9	8	6.2-10	8.3
ACL	0-12	0-9.2	2-8.5	3.1-10.4	37.5
PCL	7.5-10.8	8-9.2	8.2-14.4	10.4-18	20.8
LCL	3.2-10.8	3.2-8	4-14.4	6-18	20.8
MCL	0-3.2	0-7.9	4.5-8.5	7.5-12	16.6

Statistical analysis revealed a significant correlation between LPD and LPW measurements on both plain radiographs and CT scans and the presence of ligamentous and meniscal injuries detected on MRI.

Table 9: Association of X-ray Parameters with MRI Findings

X-ray	Patients with MRI Finding of Ligaments & Meniscal Injury	p-Value
LPD (mm)		**0.06**
0-5 (n=10)	6 (Yes), 4 (No)	
6-10 (n=11)	11 (Yes), 0 (No)	
11-15 (n=3)	2 (Yes), 1 (No)	
LPW (mm)		**0.10**
0-5 (n=15)	11 (Yes), 4 (No)	
6-10 (n=7)	7 (Yes), 0 (No)	
11-15 (n=1)	1 (Yes), 0 (No)	
21-25 (n=1)	0 (Yes), 1 (No)	

p-value ≤0.05 is significant

Table 10: Association of CT Parameters with MRI Findings

CT	Patients with MRI Finding of Ligaments and Meniscal Injuries	p-value
LPD (mm)		**0.04**
0-5 (n=8)	4 (Yes), 4 (No)	
5-10 (n=15)	14 (Yes), 1 (No)	
11-15 (n=1)	1 (Yes), 0 (No)	

LPW (mm)		0.05
0-5 (n=9)	5 (Yes), 4 (No)	
6-10 (n=12)	12 (Yes), 0 (No)	
11-15 (n=1)	1 (Yes), 0 (No)	
16-20 (n=2)	1 (Yes), 1 (No)	

p-value ≤0.05 is significant

The CT parameters showed a statistically significant association with MRI findings of ligamentous and meniscal injuries. As the LPD and LPW increased, the number of ligaments along with menisci that were injured also increased. However, there were a few cases with no soft tissue injuries despite high LPD/LPW values, and conversely, some cases with multiple ligament injuries with minimal displacement.

In summary, our results demonstrated that CT parameters (LPD and LPW) can predict ligamentous injuries with statistical significance ($p \leq 0.05$). The minimum threshold values of LPD and LPW on plain radiographs at which ligamentous and meniscal injuries occurred were 3.2 mm and 2 mm, respectively, while on CT scans, these values were also 3.2 mm and 2 mm, respectively.

DISCUSSION:

This study investigated the correlation between radiographic parameters, specifically lateral plateau depression (LPD) and lateral plateau widening (LPW), and the presence of ligamentous and meniscal injuries in patients with proximal tibial plateau fractures. Our findings demonstrate that these radiographic measurements can serve as valuable predictors of associated soft tissue injuries, which may guide preoperative planning and surgical decision-making.

Demographic and Clinical Characteristics:

The demographic profile of our study population revealed a predominance of male patients (75%) and a higher incidence of tibial plateau fractures in the 40-60 years age group (70%). This male preponderance aligns with findings from several previous studies.[34,35] In our cohort, the male predominance could be attributed to higher exposure to road traffic accidents and occupational hazards, which were the most common mechanisms of injury. The age distribution in our study is comparable to findings by Porrino et al.[36] and Yan et al.,[37] who reported similar age ranges in their respective studies.

The left knee was more commonly affected (58.4%) in our study, which is consistent with the findings of Yan et al.[37] (70.4%) and Mahmut Tuncez et al.[38] (55.5%). This left-sided predominance might be explained by the traffic pattern in India, where driving occurs on the left side of the road, potentially exposing the left side of the body to greater risk during road traffic accidents.

Road traffic accidents constituted the most common mechanism of injury (70.8%) in our study, followed by falls from height and slip-and-fall injuries. This is in accordance with the findings of Gardner et al.[26] and Wang et al.,[39] who also reported road traffic accidents as the predominant mechanism. The high proportion of high-velocity injuries (67%) in our study population correlates with the high incidence of associated soft tissue injuries, as demonstrated by Warner et al.[40] and the Ramathibodi Hospital study,[41] which reported similar associations between injury velocity and soft tissue damage.

Fracture Patterns and Associated Soft Tissue Injuries:

In our study, Schatzker type V fractures (29.2%) were the most common pattern, followed by types I and II (25% each). This distribution differs somewhat from the findings of Wang et al.,[39] who reported a predominance of type II fractures (50%) in their cohort. The variation could be attributed to differences in the study populations, mechanisms of injury, and regional characteristics of trauma patterns.

Our study revealed a high overall incidence of associated soft tissue injuries (79.2%), with lateral meniscus tears being the most common (41.6%), followed by ACL injuries (37.5%). This is consistent with the findings of multiple previous studies,[26,39,42] which also reported a high prevalence of lateral meniscus tears in tibial plateau fractures. The predominance of lateral meniscus injuries can be explained by the biomechanics of tibial plateau fractures, where valgus forces combined with axial loading lead to lateral plateau compression and consequent injury to the adjacent lateral meniscus.[43,44]

The incidence of ACL injuries (37.5%) in our study is higher than that reported by Gardner et al.[26] (15%) and Warner et al.[40] (10%), but comparable to the findings of Stannard et al.[45] (39%). This variability may reflect differences in injury mechanisms, study populations, and diagnostic criteria. The relatively high incidence of ACL injuries in our cohort could be attributed to the predominance of high-velocity trauma and a higher proportion of complex fracture patterns (Schatzker types IV and V).

PCL injuries were observed in 20.8% of our patients, which is higher than the rates reported by Wang et al.[39] (3.7%) and Warner et al.[40] (2%).

This discrepancy could be related to the higher proportion of Schatzker type V fractures in our study, which are often associated with more extensive ligamentous damage due to their high-energy nature. Our findings support the observation by Spiro et al.[46] that articular depression correlates with an increased incidence of soft tissue injuries in tibial plateau fractures.

We found a significant association between high-velocity injuries and multiple ligamentous injuries, particularly in Schatzker types IV and V fractures. This is in line with the findings of Stannard et al.,[45] who reported that high-energy fracture patterns have a significantly higher incidence of ligament injury. Our results also corroborate those of Shepherd et al.,[47] who found a high prevalence of soft tissue injuries even in non-displaced tibial plateau fractures, emphasizing the importance of thorough evaluation regardless of fracture displacement.

Radiographic and CT Parameters as Predictors of Soft Tissue Injuries:

A key finding of our study is the identification of minimum threshold values of LPD and LPW at which specific ligamentous and meniscal injuries occurred. We found that ligamentous and meniscal injuries occurred at minimum values of LPD (3.2 mm) and LPW (2 mm) on both plain radiographs and CT scans. These thresholds are lower than those reported by Gardner et al.,[26] who suggested that plateau depression or widening approaching 5 mm raised the likelihood of concomitant soft tissue injury, and by Wang et al.,[39] who reported thresholds of 5 mm for LPD and 6 mm for LPW on plain radiographs.

Our findings suggest that even minor degrees of plateau depression and widening may be associated with significant soft tissue injuries, highlighting the need for a high index of suspicion and thorough evaluation even in seemingly less severe fractures. This is particularly important given that the clinical assessment of ligamentous integrity in the acute setting is often limited by pain and hemarthrosis.

The correlation between CT measurements and MRI findings in our study demonstrated that CT parameters (LPD and LPW) were statistically significant predictors of ligamentous and meniscal injuries ($p \leq 0.05$). This supports the findings of Hassan et al.,[48] who concluded that MDCT measurements of LPD and LPW correlate with the incidence and number of ligamentous and meniscal injuries. Similarly, our results align with those of Mui et al.,[49] who reported that CT offers high negative predictive value for excluding ligament injury.

We observed that as LPD and LPW increased, the number of injured ligaments and menisci also increased, consistent with the findings of Ringus et al.,[50] who demonstrated an association between tibial plateau depression and the likelihood of meniscal tears. However, we also noted exceptions to this pattern, with some cases showing no soft tissue injuries despite high LPD/LPW values, and conversely, some cases with multiple ligament injuries despite minimal displacement. This variability underscores the complex biomechanics of these injuries and suggests that factors beyond radiographic measurements, such as the direction and rate of applied forces, may influence the pattern of soft tissue damage.

Interestingly, our study revealed that lateral plateau widening is a superior predictor of meniscal and ligamentous injuries compared to articular depression. This finding is supported by the study conducted at the University Medical Center Hamburg-Eppendorf,[51] which reported a significant effect of increasing lateral plateau widening on the incidence of lateral meniscus lesions, lateral collateral ligament tears, and overall quantity of meniscal and ligamentous lesions in lateral tibial plateau fractures.

Clinical Implications:

The findings of our study have several important clinical implications. Firstly, they highlight the high prevalence of associated soft tissue injuries in tibial plateau fractures, emphasizing the need for comprehensive evaluation of these structures during preoperative planning. Secondly, our identification of threshold values of LPD and LPW at which specific ligamentous and meniscal injuries occur provides valuable guidance for clinicians in predicting these injuries based on readily available imaging modalities.

While MRI remains the gold standard for evaluating soft tissue injuries, it may not be universally available or feasible in all clinical settings, particularly in emergency situations or resource-constrained environments. In such scenarios, the ability to predict soft tissue injuries based on plain radiographs and CT scans becomes particularly valuable. Our findings suggest that CT parameters can reliably predict ligamentous injuries, potentially obviating the need for MRI in certain cases and facilitating more expeditious treatment planning.

The recognition and appropriate management of associated soft tissue injuries are crucial for optimizing outcomes in tibial plateau fractures. As demonstrated by Delamarter et al.,[52] instability is a major cause of unacceptable results in these

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fractures, and operative repair of collateral ligaments with appropriate treatment of the tibial plateau fracture may reduce late instability and improve overall morbidity. Similarly, Park et al.[53] reported good clinical outcomes following treatment of meniscal lesions associated with lateral tibial plateau fractures, highlighting the importance of addressing these concomitant injuries.

LIMITATIONS:

Several limitations of our study should be acknowledged. Firstly, the sample size (N=24) is relatively small, which may limit the generalizability of our findings and the statistical power of our analyses. Secondly, we were unable to verify previous meniscal pathologies, which could potentially confound the interpretation of MRI findings. Thirdly, our study did not establish the reliability of intraoperative ligament and meniscal assessment compared to MRI analysis, which would have provided additional validation of our findings.

Despite these limitations, our study provides valuable insights into the relationship between radiographic parameters and associated soft tissue injuries in tibial plateau fractures and lays the groundwork for future research in this area. Larger, prospective studies with longer follow-up periods would be beneficial to further elucidate these relationships and their impact on clinical outcomes.

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