Article

Clinical Significance of MRI-Based Measurements of Tibial Plateau Widening Width and Joint Fluid Volume During Anterior Cruciate Ligament Injuries Among Patients With Tibial Plateau Fractures

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AIM: This study aimed to explore the diagnostic value of magnetic resonance imaging (MRI)-based tibial plateau widening width (TPW) and joint effusion volume during anterior cruciate ligament (ACL) injuries among patients with tibial plateau fractures.
METHODS: This retrospective study collected clinical data from 100 patients with tibial plateau fractures admitted between February 2022 and February 2024. The findings from arthroscopy or surgical intervention served used as the "gold standard". Based on the ACL injury, patients were divided into the injury group (62 cases) and the control group (38 cases). General data were compared between the two groups. Furthermore, TPW and joint effusion were assessed using MRI outcomes, and the diagnostic value of these indices in ACL injury was evaluated. Additionally, the diagnostic efficacy of these indices was assessed using the Receiver Operating Characteristic (ROC) curve, Area Under Curve (AUC), sensitivity, and specificity. Moreover, patients were followed-up for three months after surgery, and the relationship between postoperative knee function recovery, TPW, and joint effusion was evaluated.
RESULTS: The injury group demonstrated a significantly higher TPW than the control group ($p < 0.001$). Similarly, the joint effusion volume was significantly greater in the injury group compared to the control group ($p < 0.01$). The AUC of TPW was 0.826 (95% confidence interval (CI): 0.745–0.906), with a sensitivity of 66.10% and a specificity of 89.50%. However, the AUC of joint effusion was 0.691 (95% CI: 0.579–0.803), with a sensitivity of 85.50% and a specificity of 52.60%. Furthermore, the AUC of the joint index was 0.864 (95% CI: 0.793–0.936), with a sensitivity of 80.60% and a specificity of 86.80%. Additionally, correlation analysis revealed a negative correlation between TPW (r = –0.355, $p < 0.001$), joint effusion (r = –0.375, $p < 0.001$), and postoperative knee function recovery.
CONCLUSIONS: MRI-measured TPW and joint effusion volume hold significantly diagnostic value in assessing ACL injuries associated with tibial plateau fractures and correlate with the patient's postoperative knee functional recovery. These metrics may provide clinicians with important diagnostic and prognostic insights and help formulate individualized treatment plans.

Keywords: magnetic resonance imaging; widening width of tibial plateau; joint effusion; tibial plateau fractures; anterior cruciate ligament

Introduction

Tibial plateau fractures represent a common type of intra-articular injury, accounting for approximately 1% to 2% of all fractures in adults [1]. These fractures predominantly affect young adults and are often caused by high-energy trauma, such as car accidents or falls. However, low-energy injuries in the elderly may also result in tibial plateau fractures [2]. These injuries are about three times in males than in females [2]. The current clinical treatment approaches primarily aim to restore the patient's joint surface anatomy, maintain knee joint stability, preserve the normal length and alignment of the lower limb, and support early knee joint mobility [3]. Usually, tibial plateau fractures involve a lateral split of the tibial plateau, with articular surface collapse and substantial soft tissue injuries. The Schatzker classification system categorizes the extent of bony structural damage [4]. The tibial plateau fractures are often associated with soft tissue lesions, with meniscal tears found in up to 91% of patients and anterior cruciate ligament (ACL) injuries observed in 75% of individuals [5,6]. A study by Milinkovic demonstrated untreated ligament rupture as the primary cause of postoperative knee instability in individuals with tibial plateau fractures [7], highlighting the significance of accurate diagnosis and treatment of concomitant soft tissue lesions.

Tibial plateau widening (TPW) is defined as the horizontal widening of the proximal tibial articular surface following a tibial plateau fracture [8]. This expansion is the result of the collapse or displacement of the articular surface of the tibial plateau, which is caused by the fracture. TPW acts as an indicator of fracture severity, helps in determining the

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fracture type, and has been used as an imaging risk factor to predict meniscal injuries in previous study [9]. A study by Jain A *et al.* [10] revealed that tibial plateau fractures are associated with soft tissue injuries, with joint widening exceeding 8 mm being the sole significant predictor of barrel-shank-like meniscus tears. Knee effusion, an excessive collection of synovial fluid in the joint, can result from either traumatic or non-traumatic factors. In the cases of a tibial plateau fracture, the rupture of a blood vessel at the fracture site allows blood to enter the joint cavity, inducing an inflammatory response. This response leads to the release of chemical mediators by inflammatory cells, which increases vascular permeability and allows an influx of fluid and inflammatory cells to infiltrate the joint cavity, resulting in effusion [11].

The ACL is crucial in maintaining knee joint stability. Patients with combined ACL injuries experience decreased knee stability, further damaging the joint structure; furthermore, ACL injuries are often accompanied by concomitant peripheral soft tissue injuries, such as meniscus, joint capsule, and synovium, which can exacerbate inflammatory responses and result in elevated fluid accumulation [12]. Preoperative magnetic resonance imaging (MRI) provides good soft tissue resolution for patients with tibial plateau fractures associated with soft tissue lesions, allowing the identification of intra-articular meniscal and cruciate ligament injuries within the joint [13]. However, intra-articular hematoma can interfere with imaging, resulting in an overdiagnosis of soft tissue lesions and false positive outcomes [14]. A better understanding of the preoperative soft tissue lesions could significantly affect the surgical strategy for patients with tibial plateau fractures [15]. Risitano S *et al.* [16] reported that MRI often determined the need for additional surgeries for ACL and posterior cruciate ligament injuries. Therefore, it is crucial to identify a more precise index for diagnosing associated soft tissue lesions in these patients. This would help optimize surgical treatment plans and reduce unnecessary surgical interventions.

This study aimed to explore the diagnostic value of MRI-based TPW and joint effusion volume in identifying ACL injuries in tibial plateau fracture patients. Our study contributes to the existing knowledge by revealing that TPW and joint effusion volume are valuable indicators for diagnosing ACL injuries and predicting postoperative knee function recovery in these patients. These findings can assist clinicians in developing personalized treatment plans, ultimately improving patient outcomes.

Materials and Methods

Study Population

This retrospective study collected clinical data from 100 tibial plateau fracture patients admitted between February 2022 and February 2024. Arthroscopic findings were used as the ‘gold standard’ for diagnosing ACL injuries. Based on the ACL injury, patients were divided into the injury group (n = 62) and the control group (n = 38). This study was approved by the Ethics Committee of Mianzhu People’s Hospital (Approval number: 20250120003). The study design followed the principles and regulations of the Declaration of Helsinki. Furthermore, the informed consent form was signed by all study participants.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (a) patients with a history of trauma presented knee pain, swelling, limited motion, and a preoperative diagnosis of tibial plateau fractures with suspected ACL injury; (b) patients with a closed tibial plateau fracture, undergoing surgical procedure within 21 days of injury; (c) the injury group diagnosed with ACL injury through arthroscopy or surgery, while the control group had intact ACLs; (d) patients aged between 18 and 55; (e) patients using intraoperative arthroscopic evaluation; and (f) those with complete clinical data.

The exclusion criteria included patients with (a) open or pathological fracture; (b) knee inversion, valgus deformity, or peripheral tumor; (c) other ligament injuries, such as posterior cruciate ligament or medial and lateral collateral ligaments; (d) chronic arthritis or chronic joint injuries; (e) concurrent malignant tumors; (f) history of previous knee surgery; (g) mental disorder; and (h) poor MRI image quality.

Patient Examination Protocol

An 8-channel knee-phased array coil was used with a GE 1.5T Magnetic Resonance Imaging System (1.5-tesla magnetic field strength, General Electric, Milwaukee, WI, USA). Patients were positioned supine with the knee joint straightened and the affected knee externally rotated by 20°, placed in the center of the coil, and instructed to maintain the posture. The scanning range centered on the knee joint, extending 3–5 cm above the femoral condyle and down to the upper tibia, selecting sagittal, coronal, and cross-sectional plans with a scanning matrix of 256 × 256.

Parameters were set as follows:

▪ Sagittal plane: Echo Time (TE) = 40 ms, Repetition Time (TR) = 350 ms, layer spacing = 0.5 mm, layer thickness = 4.0 mm, Field of View (FOV) = 20.0.

▪ Coronal plane: TE = 75 ms, TR = 2000 ms, layer spacing = 0.5 mm, layer thickness = 4.0 mm, FOV = 19.0.

▪ Transverse plane: TE = 140 ms, TR = 2000 ms, layer spacing = 0.5 mm, layer thickness = 4.0 mm, FOV = 18.0.

The images were independently analyzed by two experienced radiologists, and any disagreements were discussed to reach a consensus.

Joint effusion was evaluated using a standardized scale ranging from 0 to 3, with specific criteria based on the volume of fluid observed on MRI. Grade 0 indicated no effusion, Grade 1 represented mild effusion with fluid covering less than 25% of the synovial space, Grade 2 indicated moderate effusion covering 25%–50% of the synovial space, and Grade 3 represented severe effusion covering more than 50%. This approach ensures a more objective and reliable grading of joint effusion compared to subjective assessments [17].

TPW was measured using Mimics 19.0 software (Materialise, Leuven, Belgium), and the distance from the tangent line of the lateral femoral condyle to the most distal end of the cleavage fracture block was defined as the TPW with the average of three measurements taken [18].

Surgical Interventions

After admission, all patients received routine treatment to reduce swelling and pain, followed by plaster fixation after the edema subsided, with surgery performed within 2 weeks. Preoperative evaluations were performed to ensure thorough surgical assessment. Arthroscopy-assisted percutaneous reduction and internal fixation employing a minimally invasive strategy were performed. A STRYKER 988i orthopaedic arthroscope (Orthopaedic arthroscope model, Stryker Corporation, Kalamazoo, MI, USA) was used, with the patient positioned supine and undergoing epidural block anesthesia. The procedures were conducted by professional arthroscopists. For patients with complete avulsion and fracture, secondary ligament reconstruction was performed after proper bone healing and the restoration of 120° knee joint flexion and extension.

Observation Index

General data, including gender, age, body mass index (BMI), educational level, fracture cause, injured side, time from injury to visit, time from injury to surgery, and the Schatzker classification, were collected for the patients. Arthroscopic or surgical findings were used as the 'gold standard' to classify ACLs into injury and control groups based on their arthroscopic morphology. The diagnostic value of TPW and joint fluid volume measured by MRI for identifying ACL injury in tibial plateau fracture patients was analyzed, and the sensitivity, specificity, and accuracy were calculated. Three months after surgery, patients returned for follow-up, and knee function was assessed using the Hospital for Special Surgery (HSS) Knee Score, with a score of 100. This score includes pain (30 points), function (22 points), range of motion (18 points), muscle strength (10 points), flexion deformity (10 points), and joint stability (10 points). A higher score suggests better postoperative knee joint function recovery [19].

Statistical Analysis

Statistical analyses were performed using SPSS 23.0 (IBM, Armonk, NY, USA). Before statistical analysis, continuous variables were assessed for normality using the Kolmogorov-Smirnov test. Continuous variables were expressed as mean $\pm$ standard deviation, and the differences between groups were analyzed by t-test or Analysis of Variance (ANOVA). Categorical variables were presented as frequencies and percentages, and differences between groups were evaluated using the chi-square and Fisher's exact tests. Logistic regression equations were employed to identify factors influencing ACL injuries. The diagnostic value of TPW and joint effusion volume were evaluated using the Relative Operating Characteristic curve (ROC), Area Under Curve (AUC), sensitivity, and specificity. An AUC value closer to 1 suggests a more accurate diagnostic test. Hosmer-Lemeshow goodness of fit test was used to evaluate the calibration degree of logistic regression model. Sensitivity reflects the ability of the test to identify actual positive cases, while specificity demonstrates the ability of the test to correctly identify actual negative cases. High sensitivity and specificity indicate reliability of test results. The Pearson correlation test was applied to determine the relationship between postoperative knee function scores and TPW and joint effusion volume. A two-sided p-value of $<$0.05 was considered statistically significant.

Results

MRI Findings

Typical MRI images of tibial plateau fracture patients complicated by ACL injury are shown in Figs. 1,2.

Comparison of Baseline Data Between the Two Groups

There were no significant differences between the two groups regarding gender, age, BMI, educational level, fracture cause, injured side, time from injury to visit, time from injury to surgery, and the Schatzker classification (all $p >$ 0.05). However, the TPW was substantially greater in the injury group (7.80 $\pm$ 2.14 mm) than in the control group (5.36 $\pm$ 1.34 mm), with a statistically significant difference between the groups ($p < 0.001$). Additionally, the amount of joint effusion demonstrated a significant difference between the two groups ($p < 0.001$). The comparison between the injury and control groups is detailed in Table 1.

Identification of Risk Factors for ACL Injury

The occurrence of ACL injury in tibial plateau fracture patients was treated as the dependent variable Y (yes = 1, no = 0), with TPW and the amount of joint effusion as the dependent variable X. TPW was substituted by its actual value, and joint effusion was categorized as mild = 0, moderate/severe = 1. Thus, a binary logistic regression model was established. The model analysis results showed that TPW and joint effusion were potential risk factors for ACL injury (Table 2). The Hosmer-Lemeshow goodness of fit test demonstrated $p > 0.05$ (χ^2 = 7.084, p = 0.528), indicating that the model had fit well.

Comparison of Diagnostic Efficacy

Comparing the diagnostic value of TPW joint effusion volume, and their combination for ACL injury, demonstrated the AUC of 0.826 (0.745–0.906) for TPW. The optimal cut-off value for TPW was determined by the ROC curve,

Fig. 1. Clinical diagnosis of right tibial plateau fractures and right knee anterior cruciate ligament injuries. (A) Sagittal MRI of the right knee, indicating visible thickening of the anterior cruciate ligament alignment and mixed signals. (B) Coronal MRI of the right knee, with visible plateau fracture and soft tissue swelling. (C) Transverse MRI of the right knee, indicating visible plateau fractures, widening, and fracture line involving the anterior cruciate ligament stopping point. MRI, magnetic resonance imaging.

Fig. 2. Clinical diagnosis of comminuted fractures of the right tibial plateau and injuries to the anterior cruciate ligament of the right knee. (A) Sagittal MRI of the right knee, with visible plateau fractures involving the tibial stop of the anterior cruciate ligament, soft tissue swelling, and fluid in the joint cavity. (B) Coronal MRI of the right knee indicating visible plateau fractures with partial widening, upward displacement of the bone mass at the tibial stop of the anterior cruciate ligament, soft tissue swelling, and fluid in the joint cavity. (C) Transverse MRI of the right knee, indicating visible right tibial plateau fractures, with significant displacement and widening.

selecting the point on the curve that maximized the Jorden index (sensitivity + specificity –1), which indicates the best balance between sensitivity and specificity for detecting joint effusion. The optimal cut-off value was 7.06, with a sensitivity of 66.10%, and a specificity of 89.50%. The AUC for joint effusion volume was 0.691 (0.579–0.803), with a sensitivity of 85.50% and a specificity of 52.60%. Combining TPW with joint effusion volume revealed the highest diagnostic efficacy for ACL injury, with an AUC of 0.864 (0.793–0.936), sensitivity of 80.60%, and specificity of 86.80% (Table 3, Fig. 3).

Postoperative Knee Function Score

Patients were followed up three months after surgery. The HSS scores ranged from 70 to 88 points, averaging 78.24 $\pm$ 5.31. The injury group exhibited an average HSS score of 76.41 $\pm$ 4.45, while the control group demonstrated an average score of 81.23 $\pm$ 5.29, indicating a statistically significant difference between the two groups ($p < 0.001$, Fig. 4A). Using the optimal TPW cut-off value of 7.06 mm, postoperative HSS scores were compared between groups. The average HSS score of patients with TPW <7.06 mm (n = 55) was 79.62 $\pm$ 5.75, while those with TPW $\geq$7.06 mm (n = 45) were 76.56 $\pm$ 4.20. The score difference was statistically significant (p = 0.004, Fig. 4B). Furthermore, the postoperative HSS score varied with the amounts of joint effusion. Patients with a mild amount of joint effusion (n = 29) exhibited an average score of 81.34 $\pm$ 5.77, those with a moderate amount of joint effusion (n = 38) showed a score of 77.00 $\pm$ 5.08, and patients with severe effusion (n = 33) scored 76.95 $\pm$ 3.99, with the difference being statistically significant ($p < 0.001$, Fig. 4C).

Table 1. Comparison of general information.

Variables		Injury group (n = 62)	Control group (n = 38)	χ^2/t	p-value
Gender [n (%)]	Male	35 (56.45)	21 (55.26)	0.014	0.908
	Female	27 (43.55)	17 (44.74)		
Age ($\bar{x} \pm$ s, years)		41.84 ± 9.14	42.37 ± 8.26	0.292	0.771
BMI ($\bar{x} \pm$ s, kg/m^2)		24.54 ± 2.71	24.76 ± 2.58	0.401	0.689
Educational level [n (%)]	Junior high school and below	14 (22.58)	8 (21.05)	0.553	0.759
	High school or technical secondary school	28 (45.16)	15 (39.47)		
	College or above	20 (32.26)	15 (39.47)		
Cause of fracture [n (%)]	Traffic accident	33 (53.23)	21 (55.26)	1.154	0.764
	Fall	10 (16.13)	8 (21.05)		
	Heavy objects	11 (17.74)	4 (10.53)		
	Sports	8 (12.90)	5 (13.16)		
Injured side [n (%)]	Left	27 (43.55)	17 (44.74)	0.014	0.908
	Right	35 (56.45)	21 (55.26)		
The time from injury to medical attention ($\bar{x} \pm$ s, d)		1.26 ± 0.26	1.24 ± 0.23	0.390	0.698
The time from injury to surgery ($\bar{x} \pm$ s, d)		7.54 ± 1.37	7.28 ± 1.28	0.944	0.347
Schatzker typing [n (%)]	I	8 (12.90)	7 (18.42)	1.083	0.956
	II	10 (16.13)	6 (15.79)		
	III	21 (33.87)	10 (26.32)		
	IV	15 (24.19)	9 (23.68)		
	V	5 (8.06)	4 (10.53)		
	VI	3 (4.84)	2 (5.26)		
TPW ($\bar{x} \pm$ s, mm)		7.80 ± 2.14	5.36 ± 1.34	6.305	<0.001
Fluid accumulation in the joints [n (%)]	Mild	9 (14.52)	20 (52.63)	16.656	<0.001
	Moderate	28 (45.16)	10 (26.32)		
	Severe	25 (40.32)	8 (21.05)		

BMI, body mass index; TPW, tibial plateau widening width.

Table 2. Multifactor logistic regression analysis to identify risk factors for ACL.

Factors	β	SE	Wald	p-value	OR (95% CI)
TPW	0.680	0.161	17.837	<0.001	1.975 (1.440–2.708)
Fluid accumulation in the joints	1.624	0.575	7.990	0.005	5.074 (1.645–15.648)
Constant	–5.028	1.123	20.063	<0.001	0.007

SE, standard error; OR, odds ratio; ACL, anterior cruciate ligament; CI, confidence interval.

Table 3. Diagnostic performance of TPW and joint effusion volume.

Index	AUC	Sensitivity (%)	Specificity (%)	95% CI	Jorden index	p-value
TPW	0.826	66.10%	89.50%	0.745–0.906	0.556	<0.001
Fluid accumulation in the joints	0.691	85.50%	52.60%	0.579–0.803	0.381	0.001
Joint forecasting	0.864	80.60%	86.80%	0.793–0.936	0.674	<0.001

TPW, tibial plateau widening width; AUC, Area Under Curve.

Correlation of TPW, Joint Effusion Volume, and Postoperative Knee Function Score

Pearson correlation analysis of TPW, joint effusion volume, and postoperative knee function score revealed that the HSS score was negatively correlated with TPW (r = –0.355, $p <$ 0.001) and joint effusion volume (r = –0.375, $p <$ 0.001). Correlation analysis is summarized in Table 4.

Discussion

The human knee joint is complex in structure and function, whereas the tibial plateau has loose and relatively fragile lateral bone, making it highly susceptible to fracture from external forces [20]. Tibial plateau fractures affect the knee joint surface, resulting in instability in the primary weight-bearing joint, leading to lateral tibial plateau cleavage and

Table 4. Correlation between TPW, joint effusion volume, and postoperative knee function score.

Index	Correlation	Significance	Standard error	95% CI	
				Lower bound	Upper bound
TPW	–0.355**	<0.001	0.082	–0.509	–0.186
Fluid accumulation in the joints	–0.375**	<0.001	0.094	–0.554	–0.185

**, correlations are significant at a confidence level (two-sided) of 0.01.

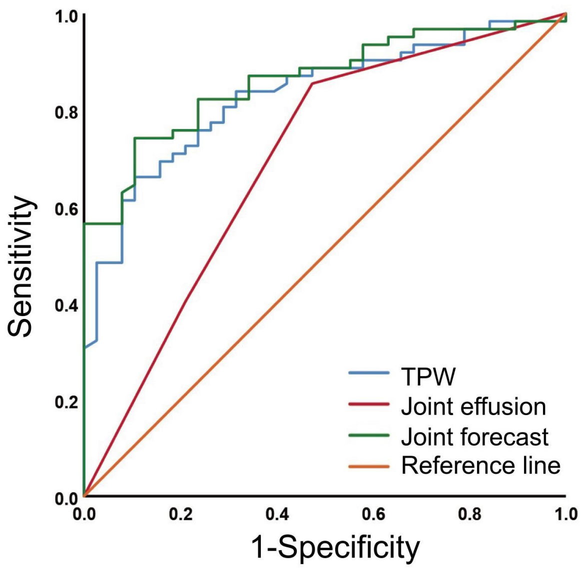

Fig. 3. ROC curve of TPW and joint effusion volume. TPW, tibial plateau widening width; ROC, Receiver Operating Characteristic.

compression collapse of the articular surface [21]. Therefore, timely surgical intervention is crucial to avoid poor knee joint recovery, limited mobility, or even lower limb disability [22]. In clinical practice, tibial plateau fractures frequently occur in conjunction with cruciate ligament injuries due to the substantial anterior displacement of the proximal tibia, which results in increased tension on the ACL, thereby elevating the risk of injury. The ACL is the primary stabilizer of the knee joint, connecting the tibia and femur, preventing anterior and rotational tibial during knee extension [18].

Nevertheless, the precise interpretation of ligament damage in imaging can be challenging. Edematous ligament and surrounding tissues exhibit low signal intensity, which complicates the differentiation of ligament tissue injuries. Zhang Y *et al*. [23] highlighted that the loss of normal anatomical structures and the formation of intra-articular hematoma following a tibial plateau fracture can impact the accuracy of MRI assessment. The MRI findings in our study demonstrated that the tibial plateau fracture exhibited a more distinct fracture line within the bone trabeculae, interruption of the continuity of the bone cortex, and a predominantly tibial stop of the ACL fracture line. Additionally, joint effusion was observed, indicating that tibial plateau fractures significantly impact both the skeletal structure and the soft tissues of the joint, particularly the ACL, emphasizing further clinical investigation and attention.

We observed that patients with tibial plateau fractures and ACL injuries exhibited elevated TPW measurements and more pronounced joint effusion. It is hypothesized that the trauma caused by a tibial plateau fracture results in vascular rupture, inducing fibrinolysis and damaging the mucosal proteins of the vascular basal lamina, leading to tissue damage surrounding the hematoma [24]. The subsequent inflammatory response from blood exudation impairs circulation, leading to limb swelling. The inflammatory response, along with the hematoma, increases vascular permeability, allowing leakage of inflammatory mediators into the joint cavity, including plasma, cells, cytokines, and prostaglandins, contributing to the formation of joint effusion [25]. The ligaments are rich in blood vessels and nerves, exacerbating a series of responses after an injury. Additionally, ligament injury leads to joint instability, increasing friction and impingement between joint surfaces, thereby stimulating joint fluid secretion. Consequently, tibial plateau fractures with concomitant ACL injuries can often be associated with more pronounced and severe joint effusion [26]. A tibial plateau fracture entails the articular surface, where compression or collapse can result in bone fragmentation and displacement. The compressed or collapsed fracture may displace inwards or outwards into the joint cavity, rendering the originally flatter articular surface uneven and altering its geometry. This displacement increases the width of the tibial plateau and elevates the risk of articular subluxation or dislocation [27].

Deng XT *et al*. [28] examined 216 cases of tibial plateau fractures, demonstrating that 17.1% involved ligament injuries, with ACL injury being the most common. These injuries were most frequently linked to Schatzker type II and type IV fractures. In contrast, a study by Wang B *et al*. [29] reported that 94 (83.2%) out of the 113 patients with posterior lateral tibial plateau fractures had ACL injuries. This study underscored the importance of determining the percentage of articular surface loss and fracture depression angle in identifying complete ACL tears in situ. The findings demonstrate a strong correlation between proximal tibial fracture dislocation and ligament rupture. Furthermore, assessing ACL injury enables surgeons to gain a thorough understanding of the overall patient injury, which helps in the formulation of a comprehensive clinical treatment plan [30].

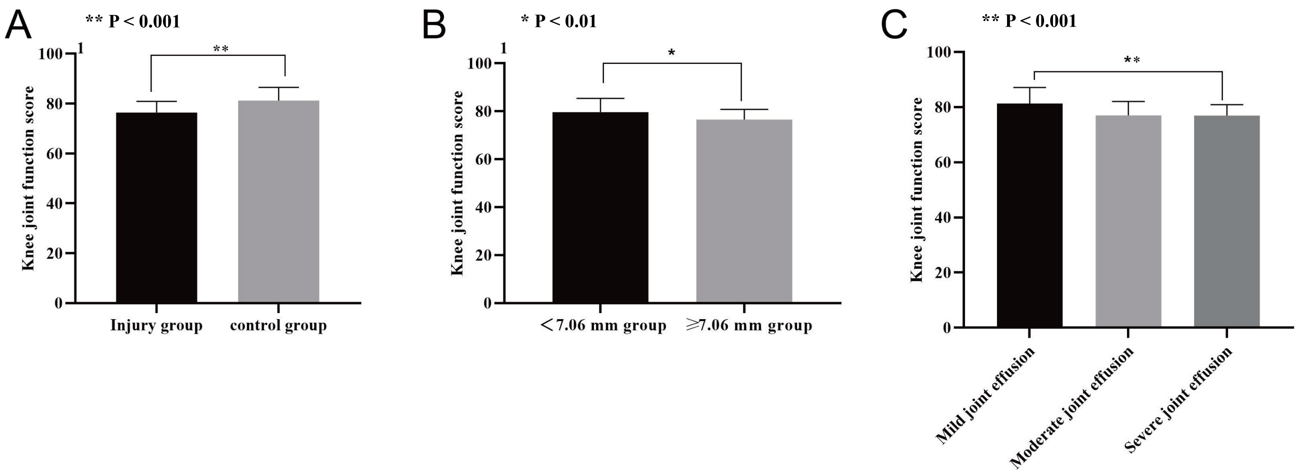

Fig. 4. Comparison of postoperative knee function score between the two groups. (A) Between injury and control group. (B) Between <7.06 mm and ≥7.06 mm group. (C) Between mild joint effusion, moderate joint effusion and severe joint effusion group.

Despite the recognized association between fractures and ligament injuries, there is currently no consensus on incorporating the comprehensive diagnosis and precise treatment of ligament injuries into the standard treatment plan for tibial plateau fractures. Several studies have indicated that ligament and meniscus injuries should be a crucial consideration when selecting treatment options for tibial plateau fracture patients [31,32]. In the event of ligamentous injuries or other sources of instability being present during fracture surgery, it is imperative to address these injuries or, at the very least, reduce ligament tears intraoperatively, with a view to restoring joint stability. ACL tibial stop lateral avulsion fractures are a common injury type. In such patients, arthroscopic one-stage reduction and fixation of the avulsed fracture block should be performed after the closed reduction and internal fixation of the tibial plateau fractures, if feasible. The question of whether to perform a two-stage repair and reconstruction for patients with complete ligament ruptures remain a clinical debate. Some researchers suggest that internal fixation surgery for tibial plateau fractures can realign the force line of the lower limb, restore the articular surfaces, and enhance scar formation around the knee joint, thereby promoting knee joint stability [33]. They further suggest that satisfactory clinical efficacy can still be achieved during the postoperative period, even without concomitant ligamentous injuries. However, the study concluded that for tibial plateau fracture patients with complete cruciate ligament rupture, the initial treatment should focus mainly on fracture fixation. This strategy considers the potential effect of the fracture on the establishment of a bone tunnel, thus indicating a delay in ligament reconstruction. The decision to undertake second-stage ligament reconstruction should depend upon the stability of the patient's knee following fracture fixation. A second-stage ligament reconstruction is recommended if the patient continues to exhibit anteroposterior or rotational instability after fracture healing.

The results of this study suggest that combined assessment of TPW and joint fluid volume improves the diagnostic effectiveness for ACL injury. Additionally, the indicated differences in HSS scores suggest that ACL injuries may have adversely impacted postoperative knee function recovery. Therefore, it can be hypothesized that larger TPWs and higher joint fluid volumes are crucial to postoperative recovery. Correlation analysis revealed a negative correlation between TPW, joint fluid volume, and postoperative knee function recovery, suggesting that increased TPW and joint fluid volume are associated with poorer postoperative functional outcomes. Clinicians should consider the severity of TPW and joint effusion when selecting treatment strategies and designing postoperative rehabilitation programs. Pathologic widening of TPW may lead to various complications, and insufficient recovery of TPW is directly linked to the occurrence of traumatic arthritis [34]. Although a study by Akcaalan S *et al.* [35] similarly confirmed significant difference in tibial plateau width between ACL-injured and ACL-intact groups, there remains a considerable gap in clinical research involving TPW recovery.

In clinical practice, elevated TPW and joint fluid volume may signal more severe soft tissue damage and joint instability, necessitating more aggressive surgical treatment, including ligament reconstruction and joint cleaning. High TPW and joint fluid volume could be associated with poor postoperative recovery of knee function, thereby helping surgeons set realistic expectations for patients before surgery. Furthermore, these measurements can guide the development of targeted postoperative rehabilitation programs, especially for patients requiring additional attention on TPW recovery and joint effusion management.

Nonetheless, there are some limitations to this study. Firstly, its retrospective design relied on historical medical records and transcripts, which may involve certain incomplete information or inaccurate records. This design does not fully account for all potential confounders, introducing both selection and information biases. Secondly, the study was performed at a single center with a sample size limited to 100 patients, which may limit the generalizability and extrapolation of the results. Lastly, the follow-up period was limited to three months following surgery, lacking long-term data to comprehensively assess the impact of TPW and joint effusion volume on prognosis of patients. Future studies should consider a multicenter, large-sample prospective design to validate these findings. Furthermore, long-term follow-up studies are recommended to assess the effects of TPW and joint effusion volume on long-term prognosis of patients, including knee function and quality of life.

Conclusions

This retrospective study revealed that MRI-measured TPW and joint fluid volume exhibit high diagnostic value in assessing ACL injury associated with tibial plateau fractures and are strongly linked to postoperative knee functional recovery. Our findings underscore the potential of TPW and joint fluid volume as crucial biomarkers for diagnosing ACL injuries. These measurements can enhance diagnostic accuracy and facilitate earlier detection of ACL injuries. Furthermore, TPW and joint fluid volume can offer valuable insights for surgical decision-making. Patients with large TPW or joint effusion volume may benefit from more aggressive surgical treatment and personalized rehabilitation programs. Thus, these indexes can play crucial role in guiding surgical decisions and postoperative care approaches. Particularly, patients with elevated TPW or joint effusion volume may require more aggressive surgical treatment and individualized rehabilitation plans. To improve the generalizability and reliability of these results, future studies should adopt a multicenter, large-sample, prospective design to further validate the diagnostic significance of TPW and joint fluid volume in ACL injury.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

QS contributed to the research design, data collection, statistical analysis, and manuscript drafting. GY and JD participated in data analysis and interpretation. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Mianzhu People's Hospital (Approval number: 20250120003). The study design followed the principles and regulations of the Declaration of Helsinki. Furthermore, the informed consent form was signed by all study participants.

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Conflict of Interest

The authors declare no conflict of interest.

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