Comparing the Effectiveness of Bone Grafting Versus Cannulated Screw Fixation in the Treatment of Posterolateral Tibial Plateau Compression Fractures With Concomitant ACL Injury

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Abstract
Posterolateral tibial plateau compression fractures (PTPCF) contribute significantly to knee instability and anterior cruciate ligament (ACL) reconstruction failure. The efficacy of fixation without metal implants for such cases remains uncertain. This study aims to assess the stability of isolated bone grafting fixation for PTPCF with concurrent ACL injuries. This retrospective analysis involved patients treated for concurrent ACL injuries and PTPCF in our institution. Fifty-five patients (24 males, 31 females, mean age: 49.2±13.3 years) were included. Patient data encompassed injury causation, affected side, anthropometric measures, and medical history. Fixation stability was evaluated through measurement of posterior and lateral tibial plateau inclination angles. Knee functional recovery was assessed using Rasmussen functional scores and Hospital for Special Surgery (HSS) scores. The bone grafting group attained satisfactory Rasmussen scores (28.32±0.83) and HSS knee joint function scores (95.35±1.93). The cannulated screw fixation group exhibited Rasmussen knee joint function scores of 28.73±0.90 and HSS knee joint function scores of 98.05±1.91, with no significant differences ($P>0.05$). Posterior inclination angle reduction loss was 0.19°±1.12° in the screw fixation group and 0.17°±1.01° in the bone grafting group, with no significant difference ($P>0.05$). Lateral inclination angle reduction loss was 0.02°±0.35° in the screw fixation group and 0.04°± 0.45° in the bone grafting group, with no significant difference ($P>0.05$). The use of bone grafting fixation for PTPCF with concurrent ACL injuries yielded comparable knee joint function outcomes. In uncomplicated PTPCF cases, filling and compacting the bone defect beneath the tibial plateau fracture fragment can provide satisfactory fixation, eliminating the need for additional cannulated screw fixation.

INTRODUCTION

Posterolateral tibial plateau compression fractures (PTPCF), constituting a minority (7-15%) of all tibial plateau fractures, are intricately linked with injuries to the anterior cruciate ligament (ACL) or fractures involving ACL attachment[1-4]. Fractures occurring in the posterolateral tibial plateau are significant due to their pivotal role in maintaining knee flexion stability. Such fractures commonly coincide with an elevated posterior inclination angle or an augmented lateral inclination angle of the lateral plateau[5,6]. Elevated posterior inclination or lateral inclination angles of the lateral plateau may result in heightened stress on the ACL during knee movement, closely associated with ACL injuries. This represents a significant contributor to knee instability and the potential for ACL reconstruction failure following ACL surgery[7]. Hence, in order to attain favorable clinical results and mitigate the risk of ACL reconstruction failure, managing posterolateral tibial plateau compression fractures (PTPCF) alongside ACL injury mandates a comprehensive approach. Merely focusing on ACL reconstruction is insufficient, equal emphasis must be placed on addressing PTPCF[8,9]. In cases of concurrent ACL injuries and PTPCF, certain surgeons employ arthroscopic-assisted reduction and fixation with cannulated screws[10]. Alternatively, some orthopedic surgeons opt for arthroscopic-assisted reduction and fixation combined with bone grafting as the preferred treatment approach[11]. However, the efficacy of fixation without the use of metal implants for these types of fractures remains to be definitively established. Thus, this retrospective study aimed to assess whether fixation with isolated bone grafting is sufficiently stable for treating concomitant PTPCF and ACL injuries. The hypothesis of this study posited that fixation with isolated bone grafting for PTPCF with concurrent ACL injuries can achieve stable fixation, along with satisfactory clinical and radiological outcomes, comparable to fixation with cannulated screws.

MATERIALS AND METHODS

Study Design: Retrospective study

Study Period: Feb 2022-Jan 2023

Study Area: GMR care hospital rajam

Inclusion Criteria:

- Preoperative knee joint magnetic resonance imaging (MRI) indicating ACL injury or ACL attachment avulsion fractures, with confirmation of PTPCF through three-dimensional computed tomography (3DCT).
- Presence of articular step-off of posterolateral tibial plateau fractures = 2 mm or a lateral tibial plateau posterior inclination angle of = 17°, with patients undergoing arthroscopic surgery for tibial plateau fracture reduction.
- Age of 18 years or older.
- Follow-up duration of at least 12 months.
- Availability of complete preoperative and postoperative imaging data.

Exclusion Criteria:

- Confirmation during surgery of the absence of ACL injury.
- Patients undergoing isolated ACL reconstruction or ACL avulsion fracture reduction and fixation.
- Patients with multiple injuries.
- Cases involving open fractures.
- Patients diagnosed with severe osteoarthritis.
- Age younger than 18 years.
- Follow-up duration of <12 months.
- Patients treated conservatively.

This study enrolled a total of 53 patients, consisting of 21 males and 32 females, with an average age of 47.43±14.71 years (ranging from 18-72 years). These patients were diagnosed with concurrent ACL injuries and PTPCF and underwent a one-stage procedure involving ACL reconstruction and reduction and fixation of tibial plateau fractures. Patients were categorized into two groups based on whether PTPCF was internally fixed with cannulated screws during the procedure: the cannulated screw fixation group (30 cases, including 13 males and 17 females) and the bone grafting fixation group (23 cases, including 8 males and 15 females).

Procedure: Patients were positioned supine and following the induction of general anesthesia, a series of tests including anterior and posterior drawer tests, Lachman tests, varus/valgus stress tests and assessments of knee joint flexion-extension were conducted to evaluate knee joint mobility and stability. Subsequently, with the knee joints flexed to 90 degrees, medial and lateral approaches were established. After clearance of intra-articular hematomas and synovial debris to ensure a clear surgical field, intra-articular injuries were assessed, encompassing examination for articular fracture fragments, injuries to the articular surface, ligament ruptures and meniscus tears.

In order to locate the lowest point of the articular fragment, an ACL guide was utilized to introduce a 2.0-mm Kirschner wire from the anterolateral portal, creating a 7.0-mm tunnel. This tunnel served as a pathway for elevating the collapsed articular surface using a metal tamp. The reduction of the articular surface was confirmed through arthroscopic visualization. Subsequently, a bone graft funnel was inserted into the fabricated 7.0-mm tunnel and the bone defect beneath the tibial plateau fracture fragments was filled and compacted using either allograft bone or calcium sulfate artificial bone in the bone grafting group.

In the cannulated screw fixation group, temporary stabilization was achieved using 2.0-mm Kirschner wires from the lateral plateau to the medial plateau when deemed necessary following fracture reduction. One to two 7.3-mm cannulated screws were then implanted below the fracture fragments to achieve rigid fracture fixation without the need for bone grafting.

When necessary, surgeries for meniscus reshaping or repair were conducted. For ruptures of the medial collateral ligament, conventional repair techniques were employed. In instances of ACL attachment avulsion fractures, traction reduction and fixation were accomplished using a 2-0 Ethibond suture. Autogenous hamstring tendons or gracilis tendons served as grafts for single-bundle ACL reconstruction.

Postoperative Recovery and Follow-Up: All patients received standardized postoperative recovery protocols and guidance. Beginning on the first day following surgery, quadriceps muscle strength training was initiated, along with passive knee flexion exercises at 30 degrees of flexion. After two weeks, patients began non-weight-bearing ambulation with knee joint support. At four weeks post-surgery, partial weight-bearing ambulation commenced, followed by full weight-bearing ambulation at eight weeks post-surgery. Every patient underwent a minimum follow-up period of 12 months, during which assessments of knee joint mobility, HSS knee joint function score (Hospital for Special Surgery), Rasmussen knee joint function score and pain levels assessed using the Visual Analog Scale (VAS) were conducted.

Clinical and Radiological Assessment: Patient data were collected, including factors contributing to the injury, affected side, body mass index (BMI) and pertinent medical history such as hypertension and diabetes. Radiological data, including preoperative and postoperative knee joint lateral images, 3D CT scans, and knee joint MRIs, were gathered to assess the patient's condition before and after the operation. Preoperatively, routine lower limb vascular Doppler ultrasound examinations were conducted to rule out deep vein thrombosis. In cases where no deep vein thrombosis was detected, subcutaneous administration of low-molecular-weight heparin calcium injection (4100 IU) was administered to prevent lower limb deep vein thrombosis. However, if deep vein thrombosis was diagnosed, treatment commenced with low-molecular-weight heparin calcium injection (4100 IU) every 12 hours subcutaneously. Postoperatively, lower limb sensation was evaluated to detect potential peroneal nerve damage. Follow-up assessments were conducted over a minimum period of 12 months and involved evaluating knee joint mobility (extension and flexion), knee joint VAS pain scores, Rasmussen function scores, and HSS knee joint scores to gauge postoperative knee joint function. The PACS (picture archiving and communication system) was utilized to measure radiological parameters of the tibial plateau, including the relative posterior inclination angle and the lateral tibial plateau lateral inclination angle before surgery, postoperatively and at the final follow-up, to assess the alignment of the lateral tibial plateau.

Statistical Analysis: For statistical analysis, SPSS version 26.0 (SPSS Inc., Chicago, IL, USA) was employed. Continuous variables were presented as mean±standard deviation. Independent-sample t-tests were used for comparing between-group differences. Categorical variables were assessed using Chi-square tests or Fisher's exact tests to determine disparities between the two groups. A significance level of $P<0.05$ was considered statistically significant.

RESULTS AND DISCUSSIONS

Baseline characteristics, such as patient age, gender distribution, BMI, operated side, presence of diabetes, hypertension and follow-up duration, exhibited no significant differences between the two groups ($P>0.05$) (Table 1). No instances of peroneal nerve injury were detected in either group, and no occurrences of ACL reconstruction failure were documented. Additionally, there were no notable disparities between the two groups concerning periarticular soft tissue injuries around the knee joint (such as meniscus injuries and medial collateral ligament injuries), major tibial plateau inclination types, or the occurrence of deep venous thrombosis in the lower extremities ($P>0.05$) (Table 1). This suggests that both treatment approaches were comparably effective and safe, with similar rates of perioperative complications and postoperative outcomes.

At the final follow-up, patients in the bone grafting group exhibited a mean extension angle of the knee of 0.63°±1.70° (range 0°-5°), with a mean flexion angle of 125.7°±7.45° (range 110°-140°). Meanwhile, in the bone cannulated screw fixation group, patients demonstrated a mean extension angle of 0.49°±1.5° (range 0°-5°) and a mean flexion angle of 128.50°±8.75° (range 115°-145°). There were no statistically

Table 1: Baseline data comparison

Variable	Cannualted screw fixation group	Bone grafting fixation group	p-value
Numbers	30	25	
Sex (male/female)	14/16	10/15	0.523
Age	47.50 ± 15.52	49.2 ± 13.3	0.629
BMI	25.4 ± 2.3	25.8 ± 1.9	0.878
Injury side (left/right)	15/15	11/14	0.814
Hypertension	5	6	0.476
Diabetes	5	3	0.689
Injury causes			
Traffic accident	24	14	
Sports injury	04	06	
Fall	02	05	
Medial collateral ligament injury	18	13	0.742
Meniscus injury	23	18	0.964
Thrombosis3	3	3	1.000
Type of plateau inclination			
Posterior inclination			
Lateral inclination	21	14	
	09	11	
	21	23	0.155
ACL Reconstruction			

Table 2: Comparision of clinical outcome

Variable	Cannualted screw fixation group	Bone grafting fixation group	p-value
Follow up (months)	16.10±2.5	14.7±3.5	0.663
VAS	0.29±5.3	0.55±0.6	0.121
Range of motion			
Extension (°)	0.49±1.5	0.63±1.7	0.733
Flexion (°)	128.50±8.75	125.7±7.45	0.242
Rasmussen functional score	28.73±0.90	28.32±0.83	0.052
HSS SCORE	98.05±1.91	95.35±1.93	0.355

Table 3: Comparison of radiological outcome

Variable	Cannualted screw fixation group	Bone grafting fixation group	p-value
Lateral tibial plateau posterior inclination			
Pre operative	32.95±7.05	31.22±6.95	0.383
Post operative	15.35±1.65	16.02±1.35	0.150
Final follow up	14.80±1.30	15.30±1.12	0.085
Reduction loss (°)	0.19±1.12	0.17±1.01	0.940
Lateral tibial plateau lateral in clinatio			
Pre operative	10.65±10.90	14.06±11.90	0.441
Post operative	-0.6±1.01	-0.14±1.09	0.856
Final follow up	-0.006±1.00	-0.12±0.93	0.903
Reduction loss (°)	0.02±0.35	0.04±0.45	0.858

significant differences in knee joint mobility between the two groups (P>0.05). This suggests comparable postoperative knee joint range of motion outcomes following both treatment approaches.

The isolated bone grafting group achieved satisfactory levels of the Rasmussen score (28.32±0.83) and HSS knee joint function scores (95.35±1.93). Similarly, the cannulated screw fixation group attained a Rasmussen knee joint function score of 28.73±0.90 and an HSS knee joint function score of 98.05±1.91. Notably, there was no statistically significant difference in knee joint function scores between the two groups (P>0.05) (Table 2). This suggests that both treatment approaches resulted in comparable postoperative knee joint function outcomes.

To evaluate the consistency of maintaining articular surface reduction following bone grafting fixation, a comparison of the posterior inclination angle and lateral inclination angle of the lateral tibial plateau was conducted for patients preoperatively, postoperatively and at the final follow-up. The analysis revealed no statistically significant difference in the posterior inclination angle and lateral inclination angle of the lateral tibial plateau at both the postoperative and final follow-up time points. This indicates that both treatment groups achieved comparable outcomes in terms of maintaining the alignment of the lateral tibial plateau over time.

In the cannulated screw fixation group, the mean reduction loss in posterior inclination angle was 0.19°±1.12°, while in the bone grafting group, it was 0.17°±1.01°, with no statistically significant difference observed between the groups (P>0.05). Similarly, the cannulated screw fixation group exhibited a mean reduction loss in lateral inclination angle of 0.02°±0.35°, whereas the bone grafting group had a reduction loss of 0.04°±0.45°, with no statistically significant difference noted between the groups (P>0.05) (Table 3). These findings suggest comparable outcomes in terms of reduction loss in both inclination angles between the two treatment groups.

The findings of this study demonstrate that isolated bone grafting for the treatment of PTPCF can achieve satisfactory knee joint range of motion (with a mean extension of 0.63°±1.7° and a mean flexion of 125.7°±7.45°) as well as favorable HSS scores

(95.35±1.93) and Rasmussen score (28.32±0.83). Moreover, fixation with isolated bone grafting for the treatment of PTPCF can provide relatively stable fixation without significant loss of reduction compared to fixation with cannulated screws, with similar reductions observed in both posterior and lateral inclination angles.

ACL injuries are often accompanied by tibial plateau fractures[9,13,14]. A meta-analysis involving knee MRIs from 1047 cases of ACL injuries revealed that early knee MRIs could detect bone contusion signal changes in up to 78% of patients[15]. The presence of tibial plateau bone contusions or fractures on MRI and even impaction fractures of the tibial plateau and femoral lateral condyle, typically indicates severe knee joint trauma resulting from forceful impact leading to knee joint subluxation[2]. Tibial plateau bone contusions or impaction fractures, often accompanied by femoral lateral condyle injuries, are commonly associated with ACL injury mechanisms, which involve knee joint flexion, external rotation and valgus force. During the reduction process following knee joint subluxation, the collision between the lateral femoral condyle and the posterolateral aspect of the tibial plateau causes this injury. A typical manifestation of tibial plateau impaction fracture is a coronal plane defect in the posterolateral tibial plateau, hence it is termed the bitten apple fracture[16,17].

Bernholt *et al*. classified tibial plateau compression fractures into three major classes based on the MRI presentation of the lateral tibial plateau: posterior cortical fractures of the tibial plateau that do not involve the articular surface, posterior cortical fractures of the tibial plateau that affect the articular surface and posterior split fractures of the tibial plateau[18]. Expanding upon this classification, Menzdorf and colleagues utilized the posterior horn of the lateral meniscus as a reference point to assist in the reclassification of surgical guidelines. However, due to the significant individual variability in meniscus morphology, this approach resulted in reduced classification reliability[17].

However, the two fracture classifications mentioned did not encompass the tibial plateau compression fractures addressed in this study. Tibial plateau compression fractures, often managed with arthroscopically assisted reduction and cannulated screw fixation involving the use of a metal tamp during the reduction process, present various deficiencies, including fragmentation of articular surface fracture fragments, irregular articular surfaces, inadequate angular reduction and rotation of fracture fragments. To facilitate the use of a metal tamp for fracture reduction, the authors categorized compression fractures of the lateral tibial plateau into three types based on the primary direction of articular surface inclination: posterior inclination, lateral inclination and horizontal compression types[10]. In this study, particular emphasis was placed on posterior inclination and lateral inclination types. Unlike tibial plateau impaction fractures associated with ACL injury, which often exhibit the kissing sign on knee MRI[19], this sign is less common in knee joint MRIs with tibial plateau compression fractures associated with ACL injuries. The mechanism behind this difference may be attributed to the lateral tibial plateau compression during the forceful process of flexion and external rotation, leading to an increased posterior inclination angle or external rotation angle. This heightened stress on the ACL eventually results in ACL injury, even in the absence of knee joint subluxation. Tibial plateau articular subsidence and increased posterior inclination angle are closely linked to posterolateral instability of the knee joint and are frequently associated with a positive pivot-shift test of grade 2 or higher in knee joints[20]. A posterior inclination angle of 17 degrees or more is a significant factor in post-ACL reconstruction failure[21]. Consequently, the treatment of tibial plateau compression fractures has garnered considerable attention.

While arthroscopic reduction and cannulated screw fixation have demonstrated positive outcomes in treating tibial plateau compression fractures, excessive use of cannulated screws can lead to complications such as interference with the ACL tunnel, graft compromise and peroneal nerve damage, necessitating secondary removal. This retrospective study compared the clinical and radiographic outcomes of arthroscopic reduction with cannulated screw fixation to those of isolated bone grafting for tibial plateau compression fractures. Results indicated that merely filling and compacting bone beneath the fracture fragment can effectively provide support for reduction. No significant differences were observed in postoperative knee joint function or reduction loss between the two groups. The trabecular composition of the subchondral bone underlying the fracture fragment imposes strict requirements on screw placement, necessitating precise positioning beneath the articular surface fracture fragment to achieve effective support. Increasing trabecular bone density under the fragment through bone grafting enhances reduction support. However, neither the use of one or two cannulated screws nor isolated bone grafting achieves fixation as robust as plate fixation. During knee movement, the lateral tibial plateau experiences minimal axial load in the extended position but gradually bears more stress during flexion due to the roll-back effect of the femoral condyle. Therefore, regardless of the fixation method used, early weight-bearing knee flexion exercises should be avoided during postoperative rehabilitation.

In this study, some patients underwent calcium sulfate artificial bone grafting. This material possesses favorable biocompatibility and degradability, while also stimulating bone formation and exhibiting excellent mechanical properties. Although postoperative follow-up revealed some degree of degradation and absorption, all fractures exhibited satisfactory healing without reduction loss (Fig. 4). Other patients received allograft bone grafting for PTPCF fixation. While allograft bone may have lower mechanical performance compared to calcium sulfate artificial bone, its absorption rate is lower, approximately 10.78%[28]. During follow-up, fractures healed well with no significant reduction loss. Compared to the cannulated screw fixation group, bone grafting fixation offers several advantages, including avoiding the use of additional metal implants, reducing the risk of peroneal nerve injury during fixation and eliminating the need for secondary removal surgery.

Limitations: Limitations of this study include its retrospective design, small sample size, short follow-up duration and inherent bias in the selection of fixation methods. Additionally, the lack of a control group of patients with conservative treatment for tibial plateau fractures without ACL injuries limits the generalizability of the findings. Furthermore, the study did not provide a comprehensive classification of tibial plateau compression fractures, and it remains unclear whether bone grafting alone is sufficient for achieving optimal reduction and fixation, depending on the fracture type.

CONCLUSION

The employment of isolated bone grafting to stabilize PTPCF alongside ACL injuries revealed comparable postoperative outcomes in terms of knee joint range of motion, Rasmussen score, HSS knee joint function score and VAS score when compared to cannulated screw fixation. For uncomplicated PTPCF cases without lateral wall disruption, filling and compacting the bone defect beneath the tibial plateau fracture fragment can achieve satisfactory fixation results, eliminating the need for additional cannulated screw fixation.

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