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Morphological variants of posterolateral tibial plateau impaction fractures in the setting of primary ACL tear

Abstract

Background: Impaction fractures of the posterolateral tibial plateau commonly occur in the setting of ACL tears with considerable variability occurring in fracture size and morphology.

Purpose: The primary objective was to characterize different morphologic variants of posterolateral tibial plateau impaction fractures. The secondary objective was to investigate the association between these impaction fracture variants and concomitant meniscal and ligamentous injuries.

Study Design: Case Series; Level of evidence 4.

Methods: Patients treated for primary ACL tears and having MRI imaging available were included in this study, and MRI images were reviewed with denotation of displaced posterolateral tibial impaction fractures. A classification system was created based on morphological variants of impaction fractures; associations were evaluated using independent chi-square testing.

Results: There were 825 knees meeting the inclusion criteria, with displaced posterolateral tibial plateau impaction fractures present in 407 knees (49.3%). We observed three distinct morphological variants of lateral tibial plateau impaction fractures: (I) posterior cortical buckle not involving the articular surface, (II) posterior impaction fracture involving the articular surface [(with subtype based on (A) tibial plateau depth bone loss <10% and (B) bone loss >10%)], and (III) displaced osteochondral fragment [(with subtypes for (A) shear or (B) depressed fragment)]. Type IIIA impaction fractures showed an increased incidence of lateral meniscus posterior root tears (33.3% vs 12.4%, $p = .009$) and an increased incidence of lateral meniscal tears (83.3% vs 56.7%, $p = .024$). There was an increased incidence of MCL tears in patients with Type IIIA impaction fractures compared to those with no fracture or other fracture type (61.1% vs. 20.1%, $p < 0.001$). Type IIIB impaction fractures showed an increased incidence of lateral meniscal tears (80.0% vs. 56.2%, $p = .005$).

Conclusion: There is a high prevalence of displaced posterolateral tibial plateau impaction fractures that occur in the setting of ACL tears and they can be classified into distinct morphologic subtypes.

Posterolateral tibial plateau impaction fractures with displaced depressed or shear fragments both demonstrated an increased incidence of lateral meniscus tears, while impaction fractures with a shear fragment had an increased incidence of lateral meniscus posterior root tears and MCL tears.

Keywords: tibial plateau; impaction fracture; classification; ACL tear

For Peer Review Only:

What is known about the subject: Impaction fractures of the posterolateral tibial plateau occur in the setting of ACL tears and have been previously described. However, the literature lacks a detailed description of morphologic variants of these impaction fractures and any associations these different morphologic variants may have with concomitant meniscal or ligament injuries.

What this study adds to the existing literature: This study provides a description of observed morphologic variants of posterolateral tibial plateau impaction fractures in a large series of patients with primary ACL tears. We provide a new classification system to describe these different variants. Furthermore, this study provides the associations between different morphologic variants of posterolateral tibial plateau fractures with meniscus tears and other ligamentous injuries.

INTRODUCTION

Impaction fractures of the posterolateral aspect of the tibial plateau have previously been recognized to be associated with anterior cruciate ligament (ACL) tears.[3,4,8–10] A generalized classification system for cartilage and bone injuries of the knees has been described with major categories for bone bruises, stress fractures, tibial fractures, femoral fractures, and osteochondral fractures[4,10] and further subcategories within those major categories; however, no specific classification for posterolateral tibial plateau impaction fractures occurring in the setting of an ACL tear has been described. Much of the recent literature regarding posterolateral tibial plateau injury in the setting of an ACL tear has focused on bone bruises, sometimes described as occult or nondisplaced impaction fractures,[1,2,6,7,12,13] with little discussion of impaction fractures where displacement of the articular surface or cortical bone is present. These displaced impaction fractures appear to represent an impaction injury of increased severity compared to isolated bone contusions and warrant further investigation to determine if they are of consequence to operative management or post-operative outcomes in the setting of ACL reconstruction.

On a review of a cohort of patients with primary ACL tears, we identified displaced posterolateral impaction fractures to be a commonly found associated injury on magnetic resonance imaging (MRI) scans. We observed different morphological variants in that portion of the study. Thus, the primary objective of this study was to provide a classification system to characterize these different morphologic variants of posterolateral tibial plateau impaction fractures. The secondary objective was to investigate the association between these impaction fracture variants and concomitant meniscal and ligament injuries.

METHODS

Study Design

This study was approved following review from an institutional review board (*institution and protocol number blinded for review*). The inclusion criteria for this study was all patients with primary ACL tears treated by a single board-certified orthopaedic surgeon (*initials blinded for review*) between April 2010 and March 2019. Inclusion criteria also required patients to have available MRI images. Patients without MRI images available were excluded from this study. Of the 825 total knees meeting inclusion criteria, 805 underwent ACL reconstruction surgery while 20 did not. Demographic information and clinical information were recorded for all patients, and data from operative reports were recorded for all patients who underwent surgery. Diagnosis of meniscus tears in this study required arthroscopic confirmation.

Preoperative MRI images were reviewed for the presence of displaced lateral tibial plateau fractures. First, a binary grouping system was used to categorize all patients based on whether they had a posterolateral tibial plateau impaction fracture or not. MRI signal change at the posterolateral tibial plateau was only classified as an impaction fracture if there was displacement of subchondral or cortical bone at the posterolateral tibial plateau rim visible on sagittal MRI T1-weighted images. Nondisplaced fractures or impaction injuries with bony contusion only were not considered an impaction fracture in this study. After all patients' MRI images had been reviewed, those patients with posterolateral tibial plateau fractures were again reviewed and a classification system was developed based on observed morphologic variants. There were three major categories of posterolateral tibial plateau impaction fractures observed, with an additional subcategory created for each of the latter two categories. Type I fractures were defined as a posterior buckle of the proximal posterior cortex of the lateral tibial plateau, characterized by a superior to inferior deformity with no involvement of the articular surface (Figure 1, Figure 2). Type II fractures were defined as a posterior impaction fracture with involvement of the articular surface, resulting in a decreased lateral tibial plateau depth. These fractures demonstrate a rectangular or trapezoidal shaped bone void in the transition zone between the articular line (line y) and the line tangential to the posterior aspect of the lateral tibial plateau (line z), instead of a triangular shape in the transition zone between these lines in either a normal knee or a type I impaction fracture (Figure 3). Type II fractures were further differentiated into 2 subcategories based on the amount of bone loss present with type IIA fractures having less than 10% tibial plateau depth bone loss and type IIB having greater than 10% (Figure 1, Figure 2). Type III fractures were defined as impaction fractures resulting in a displaced bony fragment. Type III fractures were also further differentiated into two subcategories; shear fragments (IIIA) and depressed fragments (IIIB) (Figure 1, Figure 2). All posterolateral tibial plateau fractures were classified according to this classification system by two orthopaedic surgeons (*initials blinded for review*).

For differentiating type IIA and type IIB fractures, the amount of tibial plateau depth bone loss was measured for all patients with type II posterolateral tibial plateau impaction fractures, measured by two fellowship trained orthopedic surgeons (*initials blinded for review*). This measurement was performed on the sagittal view of the MRI at the center of the lateral tibial plateau (e.g. 50% of the calculated width) (Figure 3). A modified Amis and Jakob line was drawn along the subchondral bone of the lateral tibial plateau from the anterior to posterior extents of the articular surface (line y). A line perpendicular to this line was then drawn vertically, lying tangent to the posterior aspect of the proximal lateral tibia (line z). The distance from the posterior most aspect of line y to line z was represented by line x and was termed the posterior articular marginal distance. The posterior articular marginal percentage was then calculated by dividing the posterior articular marginal distance by the sum of line y and line x. Tibial plateau depth bone loss was then calculated by subtracting the average posterior articular marginal percentage calculated in a subset of patients without posterolateral tibial impaction fractures from the calculated posterior articular marginal percentage in each patient with an impaction fracture.

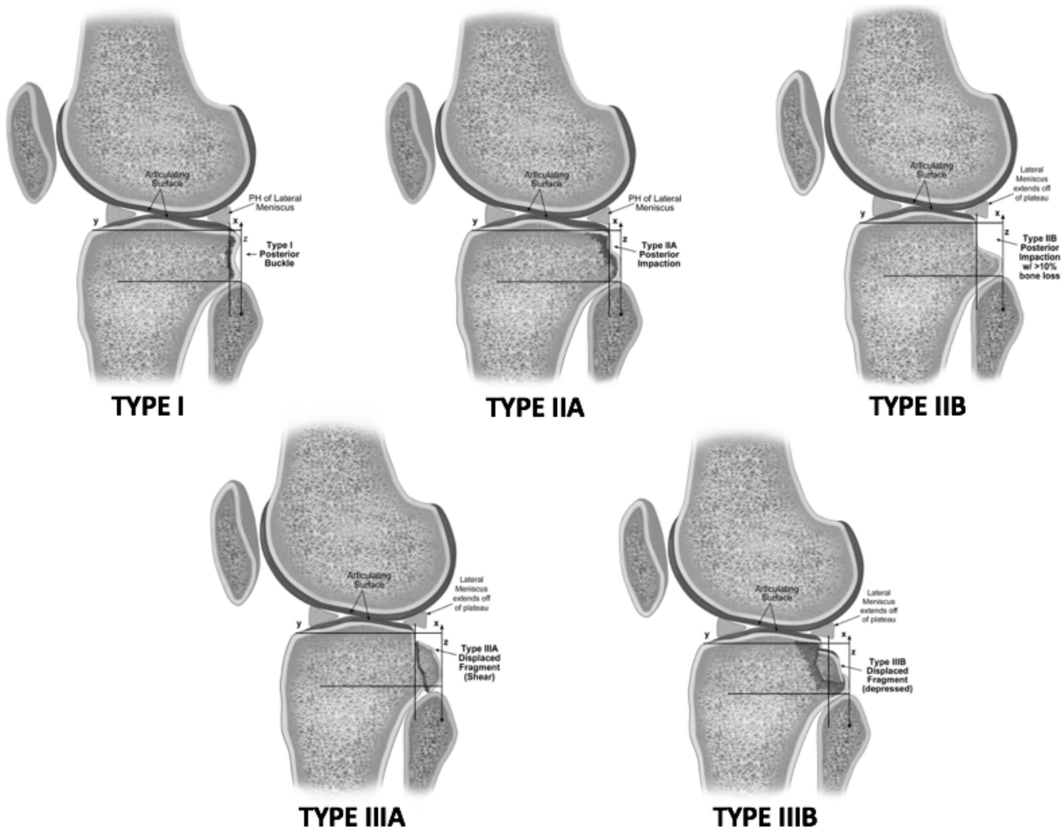

Figure 1. Sagittal illustrations (A) depicting a posterolateral tibial plateau impaction fracture classification system. Type I impaction fracture are defined as a posterior cortical impaction without involvement of the articular surface. Type II fractures are those in which there is a posterior impaction which involves the articular surface, with type IIA resulting in less than 10% tibial plateau depth bone loss and type IIB with greater than 10% bone loss. Type III fractures are defined as depressed osteochondral fractures with type IIIA being a shear fragment and type IIIB being a depressed fragment

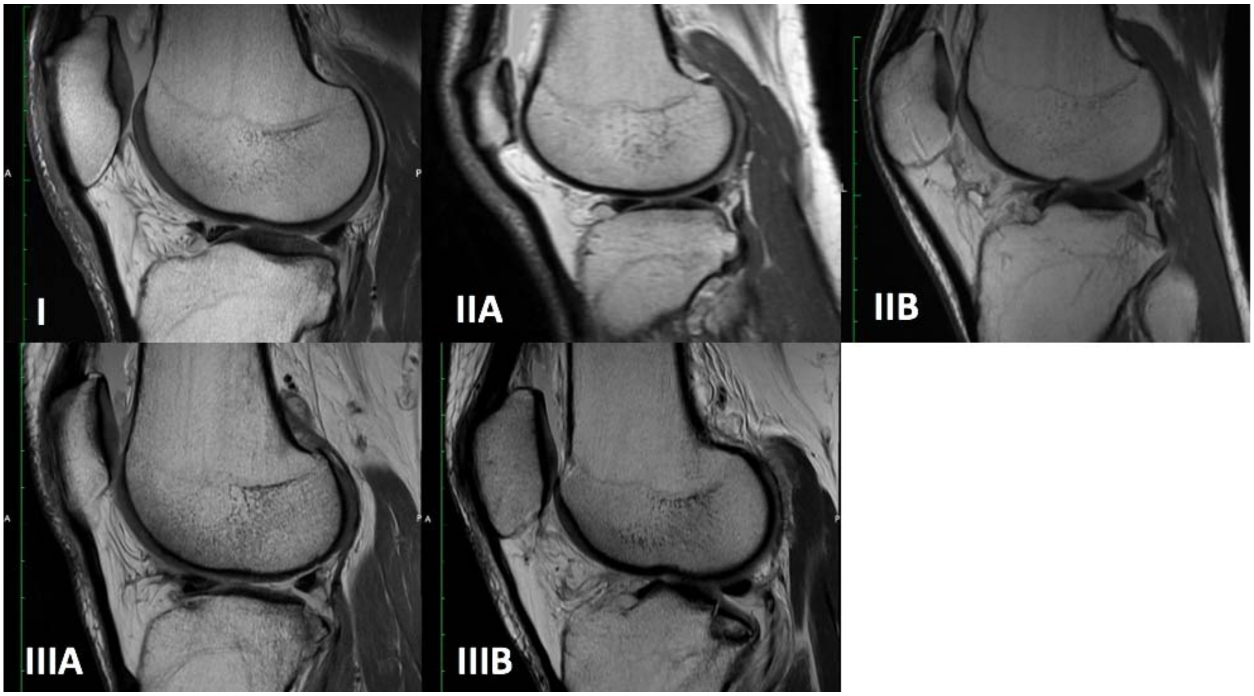

Figure 2. Sagittal MRI images showing example posterolateral tibial plateau impaction fractures based on classification system. Type I impaction fracture are defined as a posterior cortical impaction without involvement of the articular surface. Type II fractures are those in which there is a posterior impaction which involves the articular surface, with type IIA resulting in less than 10% tibial plateau depth bone loss and type IIB with greater than 10% bone loss. Type III fractures are defined as depressed osteochondral fractures with type IIIA being a shear fragment and type IIIB being a depressed fragment

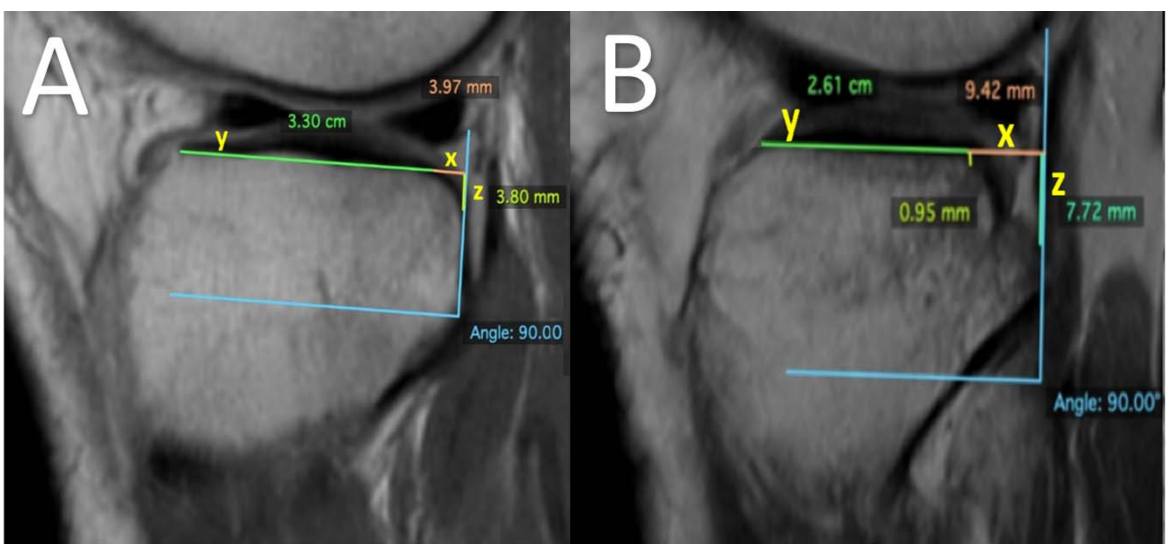

Figure 3. Tibial plateau impaction fracture measurement technique in a normal knee (A) and a knee with posterolateral tibial plateau impaction fracture (B). Sagittal image on MRI demonstrating tibial plateau depth measurements in a control knee without an impaction fracture. Line y, is drawn first along the subchondral bone from the anterior to posterior aspect of the articular surface. Next, line x, the posterior articular marginal distance, is drawn extending from the posterior extent of the articular surface to a line perpendicular to line y and placed as a tangent line along the posterior-most aspect of the proximal lateral tibia. Line z, the posterior height, is measured from the level of the articular surface

to the level where bone is first contacted along the posterior tangent line. Posterior articular marginal percentage is calculated as x/(x+y).

Statistical Analysis

Descriptive statistics were performed to determine the incidence of each type of posterolateral tibial plateau fracture based on our classification system. Clinical characteristics for patients with each type of posterolateral tibial plateau impaction fracture were analyzed to assess for correlations with meniscus tears, other ligament tears in addition to ACL tear, mechanism of injury, sex, and body mass index using chi-square testing, and ANOVA testing with post-hoc Tukey's for to analyze associations with age and body mass index (BMI). Given the difference in age between impaction fracture type, a binary logistic regression was performed with impaction fracture classification, age, and sex as the covariates with specific types of meniscal tears and knee ligament injuries as the dependent variables. Odds ratios (OR) with corresponding 95% confidence intervals (CI) were calculated for significant associations determined by logistic regression. Measurement reliability between two raters was assessed via interrater correlation coefficients (ICC) for the classification of posterolateral tibial plateau impaction fractures. All statistical analysis was performed using IBM SPSS Statistical Suite, version 25, and the alpha level was set for statistical significance at $P < 0.05$.

RESULTS

Of the 825 knees (814 patients) with primary ACL tears and available MRI images, displaced posterolateral tibial plateau impaction fractures were identified in 407 knees (49.3%). After reviewing MRIs of these knees, 198 impaction fractures were classified as Type I (48.6%), 116 as Type IIA (28.5%), 38 as Type IIB (9.3%), 19 as Type IIIA (4.7%), and 36 as Type IIIB (8.8%). Interrater reliability was calculated for a subset of 60 impaction fractures classified by two different orthopaedic surgeons and demonstrated good agreement (ICC = 0.83).

Patients with posterolateral tibial plateau impaction fractures of all classification types were significantly older than patients without an impaction fracture *(p* < .001) (Table 1). Furthermore, patients with either Type IIB or Type IIIB fractures were significantly older than patients with Type I fractures (*p* < .001). There was no difference in the BMI between any impaction fracture group or patients without fracture (*p* = 0.95). There were significant positive associations between male sex and no impaction fracture and female sex and type IIA impaction fractures (Table 2). Patients with any type of tibial impaction fracture were more likely to have a noncontact mechanism of injury compared to patients without impaction fracture (*p* < 0.001), and more specifically, patients with type I and type IIA fractures showed a higher incidence of noncontact mechanism (*p* = 0.001 and 0.02 respectively), while patients with type IIIA fractures showed a higher incidence of contact mechanism (*p* = 0.04) (Table 3).

Table 1. Mean age of patients with different types of posterolateral tibial plateau impaction fractures.

	N	Age (years)	STD	Min	Max
No fracture	418 (50.7%)	30.5	12.9	12.0	72.9
Type I	198 (24.0%)	35.4	13.0	12.9	73.4
Type IIA	116 (13.1%)	43.2	11.5	14.2	67.2
Type IIB	38 (4.6%)	52.1	9.6	33.8	72.0
Type IIIA	19 (2.3%)	41.6	14.4	18.3	73.6
Type IIIB	36 (4.4%)	47.4	14.2	17.6	72.4
Total	825	35.4	14.2	11.2	73.6

STD - standard deviation; Min – minimum; Max – maximum; TP – tibial plateau

Table 2. Independent chi-square associations between sex and posterolateral tibial plateau impaction fracture type.

	Female	Male	p
No fracture	**181/418 (43.7%)**	**237/418 (56.7%)**	**0.007**
Type I	101/198 (51.0%)	97/198 (48.9%)	0.28

Type IIA	**71/116 (61.2%)**	**45/116 (38.8%)**	**0.002**
Type IIB	20/37 (54.0%)	17/37 (46.0%)	0.45
Type IIIA	5/19 (26.3%)	14/19 (73.7%)	0.06
Type IIIB	17/36 (47.2%)	19/36 (52.8%)	0.93
Total	395/825 (48.0%)	429/824 (52.0%)	

Table 3. Independent chi-square associations between mechanism of injury and posterolateral tibial plateau impaction fracture type.

	Contact	Non-Contact	p
No fracture	**108/410 (26.3%)**	**302/410 (73.7%)**	**0.001**
Type I	**21/194 (10.8%)**	**173/194 (89.2%)**	**0.001**
Type IIA	**13/111 (11.7%)**	**98/111 (82.3%)**	**0.02**
Type IIB	7/36 (19.4%)	29/36 (80.6%)	0.95
Type IIIA	**7/18 (38.9%)**	**11/18 (61.1%)**	**0.04**
Type IIIB	3/35 (8.6%)	32/35 (91.4%)	0.09
Total*	160/805 (19.9%)	645/805 (80.1%)	

*Mechanism of injury data were not available for n=20 patients, thus these patients with missing data were excluded from this independent analysis.

There were significant associations between posterolateral tibial plateau impaction fracture type and certain meniscal injuries identified (Table 4). There were no associations between Type I or II impaction fractures and meniscal tears. Type IIIA impaction fractures showed an increased incidence of lateral meniscus posterior root tears (33.3% vs 12.4%, OR: 3.5, 95% CI: 1.3-9.7; p = .009) and an increased incidence of lateral meniscal tears (83.3% vs. 56.7%, OR: 3.8, 95% CI: 1.1-13.3; p = .024). Type IIIB impaction fractures had an increased incidence of lateral meniscal tears (80.0% vs. 56.2%, OR: 3.1 95% CI: 1.3-7.2; p = .005). We did observe a decreased incidence of medial meniscal ramp lesions in patients without impaction fracture compared to all patients with impaction fractures (16.1% vs. 21.5%, OR: 0.7, 95% CI: 0.40-1.0, p = 0.05). Given the statistically significant associations between age and sex with certain types of impaction fractures, a binary logistic regression was performed to compare meniscal tear type with impaction fracture classification, sex, and age. This showed significant associations with lateral meniscal tears and type IIIA (OR: 4.1, 95% CI: 1.2-14.5, p = 0.03) and type IIIB

(OR 3.7, 95% CI: 1.5-8.9, *p* = 0.003) impaction fractures in addition to male sex (OR: 1.7, 95% CI: 1.3-2.0, *p* = 0.001). For lateral meniscus posterior root tears, regression showed an association with type IIIA fractures (odds ratio: 3.2 (1.1-8.9); *p* = 0.03).

Table 4. Chi-Square associations between posterolateral tibial plateau impaction fracture type and various meniscal pathologies.

	Lateral meniscus tear		Lateral meniscus posterior root tear		Medial meniscus tear		Medial meniscus ramp lesion		Medial meniscus posterior root tear	
	Incidence	*p*	Incidence	*p*	Incidence	*p*	Incidence	*p*	Incidence	*p*
No Fracture	221/409 (54.0%)	0.06	51/406 (12.6%)	0.82	191/411 (46.5%)	0.28	**66/410 (16.1%)**	**0.05**	16/411 (3.9%)	0.65
Type I	110/194 (56.7%)	0.86	21/194 (10.8%)	0.34	90/194 (46.4%)	0.54	42/194 (21.6%)	0.23	2/194 (1.0%)	0.10
Type IIA	65/111 (58.6%)	0.77	13/112 (11.6%)	0.68	59/111 (53.2%)	0.27	22/111 (19.8%)	0.75	6/111 (5.4%)	0.27
Type IIB	22/37 (59.5%)	0.78	7/37 (18.9%)	0.26	19/37 (51.4%)	0.71	7/37 (18.9%)	0.98	3/36 (8.3%)	0.12
Type IIIA	**15/18 (83.3%)**	**0.02**	**6/18 (33.3%)**	**0.009**	9/18 (50.0%)	0.89	4/18 (22.2%)	0.70	0/18 (0%)	0.41
Type IIIB	**28/35 (80.0%)**	**0.005**	5/35 (14.2%)	0.79	21/35 (60.0%)	0.16	9/35 (25.7%)	0.28	1/35 (2.9%)	0.88

There were significant associations between posterolateral tibial plateau impaction fracture types and additional ligament tears in addition to the ACL (Table 5). There was an increased incidence of medial collateral ligament (MCL) tears in patients with Type IIIA impaction fractures compared to those with no fracture or other fracture type (61.1% vs. 20.1%,OR: 5.9, 95% CI: 2.2-15.4; $p < 0.001$). Both Type I and IIA fracture types showed decreased incidence of posterolateral corner (PLC) tears (1.6% vs. 6.8%, *p* = .006 and 0.9% vs. 6.3%, p = 0.023 respectively), while Type IIB showed a decreased incidence of fibular collateral ligament (FCL) tears (13.5% vs. 29.4%, *p* = .037). Binary logistic regression was performed to compare concomitant ligament tears with impaction fracture classification, sex, and age. This showed a significant association between type IIIA impaction fracture and male sex and MCL tears (OR: 5.1, 95% CI: 1.9-14.0; *p* = 0.001; and OR: 1.6, 95% CI: 1.1-2.2; *p* = 0.01; respectively). There was a decreased correlation of type I and IIA impaction fractures with both PLC tears (OR: 0.16, 95% CI: 0.05-0.53, *p* = .003; and OR: 0.09, 95% CI: 0.01-0.69, *p* = 0.02; respectively) and posterior cruciate ligament

(PCL) tears (OR: 0.31, 95% CI: 0.13-0.75, $p = 0.01$; and OR: 0.17, 95% CI: 0.04-0,72, $p = 0.02$; respectively), while male sex showed increased association with PCL tear (OR: 2.2, 95% CI: 1.2-4.3; $p = 0.01$). There were no significant associations with impaction fracture type, age, or sex with FCL tears ($p > 0.05$).

Table 5. Chi-Square associations between posterolateral tibial plateau impaction fracture type and various ligamentous pathologies.

	MCL injury		FCL injury		PLC injury		PCL injury	
	Incidence	*p*	Incidence	*p*	Incidence	*p*	Incidence	*p*
No Fracture	86/418 (20.6%)	0.31	**135/418 (32.3%)**	**0.02**	**37/418 (8.9%)**	**0.001**	**37/418 (8.9%)**	**0.001**
Type I	40/194 (20.6%)	0.59	51/194 (26.3%)	0.40	**3/194 (1.5%)**	**0.005**	**6/194 (3.1%)**	**0.05**
Type IIA	24/110 (21.8%)	0.96	31/110 (28.2%)	0.91	**1/110 (0.9%)**	**0.02**	**2/110 (1.8%)**	**0.05**
Type IIB	7/37 (18.9%)	0.64	**5/37 (13.5%)**	**0.04**	2/37 (5.4%)	0.97	1/37 (2.7%)	0.38
Type IIIA	**11/18 (61.1%)**	**0.001**	3/18 (16.7%)	0.26	0/18 (0%)	0.30	1/18 (5.6%)	0.93
Type IIIB	10/35 (28.6%)	0.34	8/35 (22.9%)	0.44	2/35 (5.7%)	0.96	2/35 (5.7%)	0.94

DISCUSSION

The main finding of this study was that there are distinct morphologic variants of posterolateral tibial plateau impaction fractures occurring in the setting of ACL tears, and that the type III variants (depressed osteochondral fractures) were both showed an increased incidence of lateral meniscal tears in the setting of primary ACL tears. In particular, we found that both displaced shear (IIIA) and depressed fragment (IIIB) types of impaction fractures had an increased incidence of lateral meniscal tears, with displaced shear fragment impaction fractures also showing increased incidence of lateral meniscus posterior root tears. Furthermore, patients with displaced shear fragment impaction fractures had a nearly six times increased odds of having an MCL tear in the setting of primary ACL tears compared to patients without these shear fractures.

The classification system established in this study has potential clinical utility because it demonstrates associations between certain posterolateral tibial impaction fracture types with concomitant meniscal and ligamentous injuries. Patients with type IIIA and IIIB fractures of the lateral tibial plateau had greater than three times increased chance of having a complete lateral meniscus tear. Type IIIA depressed sheer osteochondral fractures also had a three-fold increased odds of having a lateral meniscus posterior root tear. As a result, when these fractures are identified on MRI, there should be a heightened clinical suspicion for lateral meniscal pathology. Furthermore, when a type IIIA fracture is appreciated on MRI, there should be a heightened clinical suspicion for an MCL tear because there was a five times increase in odds between type IIIA fractures and complete grade III MCL tears. This classification system may also provide insight into the potential injury mechanism for some of the impaction fracture subtypes. We did observe an increased incidence of a contact mechanism in patients with Type IIIA fractures compared to other impaction fracture types, suggesting that this particular type of impaction fracture may occur less frequently with the typical pivot shift mechanism compared to other impaction fracture types.

We did not find that type IIB fractures, posterior impaction fractures with greater than 10% bone loss, were associated with an increased incidence of any particular type of meniscal tear or concomitant ligament tear in comparison to patients without these fractures. This does not necessarily mean that increasing bone loss associated with posterolateral tibial plateau impaction fractures is not of clinical significance. Prior studies have reported that lateral tibial plateau geometry affects the stability of the knee. One study showed that decreased tibial plateau articular depth was associated with ACL tears, while another showed that a decreased medial to lateral width of the lateral plateau was associated with greater instability on pivot shift testing.[5,11] As our study does not include post-operative outcome data, we are unable to determine the potential effect that the increased tibial plateau bone loss seen in group IIB may have on post-operative stability or ACL graft failure, and further research is required to fully understand this potential effect.

This study has some limitations. First, this study was conducted with use of MRI rather than computerized tomography (CT) scan. The utilization of CT scans could have afforded better detail of the fracture morphology and aided in characterizing fractures according to the proposed classification system. Nonetheless, our results demonstrated good interrater reliability with of the proposed classification system using MRI, which also provides a more clinically applicable method for classification as MRI is often the standard of care for evaluating ACL tears. Additionally, this study included only radiographic and operative data, which prevented us from being able to analyze the effect of different morphologic variants of posterolateral tibial plateau fractures on postoperative outcomes. As a result, this limits our ability to determine a more complete assessment of the clinical relevance of these posterolateral tibial plateau impaction fractures and whether additional measures should be considered to address these lesions when present. Future studies are needed to evaluate the biomechanical implications for such lesions on knee joint forces and stability in ACL-deficient and ACL-reconstructed knees.

CONCLUSION

There is a high prevalence of displaced posterolateral tibial plateau impaction fractures that occur in the setting of ACL tears and can be classified into distinct morphologic subtypes. Posterolateral tibial plateau impaction fractures with displaced depressed or shear fragments both demonstrated an increased incidence of lateral meniscus tears, while impaction fractures with a shear fragment had an increased incidence of lateral meniscus posterior root tears and MCL tears.

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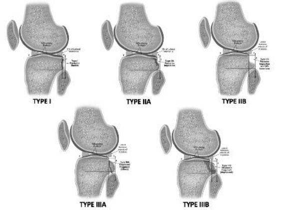
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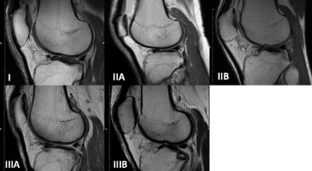
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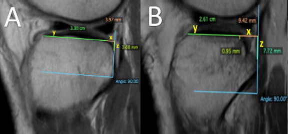
A
3.30 cm
3.97 mm
y
x
z
3.80 mm
Angle: 90.00
B
2.61 cm
9.42 mm
y
x
z
0.95 mm
7.72 mm
Angle: 90.00°