Incidence of Displaced Posterolateral Tibial Plateau and Lateral Femoral Condyle Impaction Fractures in the Setting of Primary Anterior Cruciate Ligament Tear

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Background: Bone bruising of the posterolateral tibial plateau and the lateral femoral condyle sulcus terminalis has a well-established association with anterior cruciate ligament (ACL) tears. Impaction fractures of the femur and tibia may occur in these locations; however, there is a paucity of literature describing these fractures.

Purpose: The primary objective was to quantify the incidence, size, and location of impaction fractures of the posterolateral tibial plateau and lateral femoral condyle in patients with primary ACL tears. The secondary objective was to investigate the association between impaction fractures and concomitant meniscal and ligamentous injuries.

Study Design: Case series; Level of evidence 4.

Methods: Patients with available magnetic resonance imaging (MRI) scans who were treated for primary ACL tear by a single surgeon were identified. MRI scans were reviewed with denotation of posterolateral tibial and femoral condylar contusions and displaced impaction fractures. Measurements of the lateral tibial plateau were taken in all patients with displaced lateral tibial plateau fractures and in a subset of control patients without tibial plateau fracture present to characterize the size and location of the bony lesion. Associations of impaction fractures with concomitant meniscal or ligamentous injuries were evaluated through use of chi-square testing.

Results: There were 825 knees identified with available MRI scans. Lateral tibial plateau bone bruising was present in 634 knees (76.8%), and lateral femoral condyle bone bruising was present in 407 knees (49.3%). Posterolateral tibial plateau impaction fractures were present in 407 knees (49.3%), and lateral femoral condylar impaction fractures were present in 214 knees (25.9%). Patients with posterolateral tibial plateau impaction fractures were older than patients without these fractures (42.6 vs 32.7 years; $P < .001$), whereas patients with lateral femoral condylar impaction fractures were younger (23.8 vs 32.7 years; $P < .001$). There were 71 knees (8.6%) with a posterolateral tibial plateau impaction fracture with greater than 10% loss of lateral tibial plateau depth, and this group had an increased incidence of lateral meniscus posterior root tears (22.1% vs 12.0%; $P = .02$).

Conclusion: Posterolateral tibial plateau impaction fractures occurred with a high incidence (49.3%) in patients with primary ACL tears and demonstrated an increased association with lateral meniscus posterior horn root tears as their size increased. Lateral femoral condylar impaction fractures occurred in 25.9% of patients with primary ACL tears and entailed an increased incidence of lateral meniscal tears and medial meniscal ramp lesions.

Keywords: tibial plateau; impaction fracture; ACL tear

Impaction fractures affecting the posterolateral aspect of the tibial plateau and the lateral femoral condyle have long been recognized as injuries associated with anterior cruciate ligament (ACL) injury[8,12,17,18,20,22,24]; however, most of the existing literature details occult fractures of the lateral tibial plateau and lateral femoral condyle. Occult fractures have been described as trabecular fractures, hemorrhage, and edema of the bone marrow without disruption of the cortex and cannot be detected with conventional radiography, synonymous with bone bruising or contusion.[8] Much of the prior literature regarding bone bruising associated with ACL injury has focused on injury mechanism,[14,22,24] although some investigators have studied associations between bone bruising and meniscal and other ligamentous pathologic conditions as well.[2,10,23] Displaced impaction fractures, defined as a depression of the articular or cortical surface, and displaced osteochondral fractures, defined as a discrete fragment with an intact

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chondral surface, have been described occurring at either the anterior lateral femoral condyle or posterior lateral tibial plateau in association with an ACL tear.[8] There has been little investigation of these lesions in the literature in comparison with occult fractures or bone bruising.

There is increasing recognition of the contribution of the osseous geometry of the lateral tibial plateau to knee stability.[9,13,19] Musahl et al[13] reported an association of decreased medial to lateral tibial plateau size with a high-grade pivot shift, although the effect of lateral tibial plateau depth was not assessed. Studies have demonstrated higher pivot-shift grades with increased anterior subluxation of the lateral tibial plateau,[11] a change that would effectively decrease the amount of remaining lateral tibial plateau posterior to the weightbearing axis of the lateral femoral condyle. Despite this, there has been a paucity of investigation into the incidence, size and location, and risk factors for lateral tibial plateau impaction fractures in the setting of ACL injury. Thus, the primary objective of this study was to quantify the incidence of impaction fractures of the posterolateral tibial plateau and lateral femoral condyle in patients with primary ACL tears and to characterize the size and location of these fractures. The secondary objective of this study was to investigate the association between posterolateral tibial plateau and anterior or central lateral femoral condyle impaction fractures and concomitant meniscal and other ligamentous injuries in the setting of a primary ACL tear.

METHODS

Study Design

This study was approved after review from an institutional review board (Vail Health IRB, protocol #2019-10). Demographic information and data from surgical procedure charts were collected on all patients with primary ACL tears treated by a single board-certified orthopaedic surgeon (R.F.L.) between April 2010 and March 2019. Diagnosis of meniscal injuries was recorded based on identification at time of arthroscopy only, and diagnosis of ligament injuries in addition to ACL tear was based on documentation in the operative report. Patients without available magnetic resonance imaging (MRI) scans were excluded from the study. For all patients meeting these criteria, preoperative MRI scans were reviewed by a single board-certified orthopaedic surgeon (D.L.B.) to determine whether lateral tibial plateau and lateral femoral condyle bone bruising and/or impaction fractures were present. Bone bruising was considered to be present when increased signal was present in subcortical or cancellous bone of the lateral tibial plateau or lateral femoral condyle on T2-weighted MRI scans. MRI signal change at the posterolateral tibial plateau was classified as an impaction fracture only if displacement of subchondral or cortical bone at the posterolateral tibial plateau rim was visible on sagittal T1-weighted MRI scans; this included incomplete posterolateral tibial plateau impaction injuries resulting in indentation of the cortical bone and an altered posterior cortical line. An impaction injury of the anterior or central aspect of the lateral femoral condyle was considered an impaction fracture only if there was greater than 1.5 mm depth at the sulcus terminalis, based upon previously described criteria[6] (Figure 1), or if there was a second area of concavity separate from the sulcus terminalis. For measurement of sulcus terminalis depth, a line tangential to the subchondral bone that intersects the anterior and posterior points where the concavity of the sulcus begins is drawn, and the depth from the deepest portion of the sulcus is measured perpendicular to the tangential line. Nondisplaced fractures of either the tibial plateau or femoral condyle were not classified as fractures in this study.

Measurement Technique

For all detected posterolateral tibial plateau impaction fractures, the bony lesion was measured via an OsiriX Lite picture archiving and communication system (PACS) Viewer. A standardized technique for measurement of the impaction fracture was developed. First, 3-dimensional multiplanar reconstruction was used to ensure that sagittal images were in the plane of the tibial plateau. Next, the sagittal slice at the 50th percentile of the lateral tibial plateau width was selected for measurement of lateral tibial plateau depth. A modified Amis and Jakob line was drawn along the lateral tibial plateau subchondral bone (as opposed to the medial tibial plateau parallel to the articular cortical line on lateral radiograph, as originally described by Amis and Jakob[1]); the lateral tibial plateau

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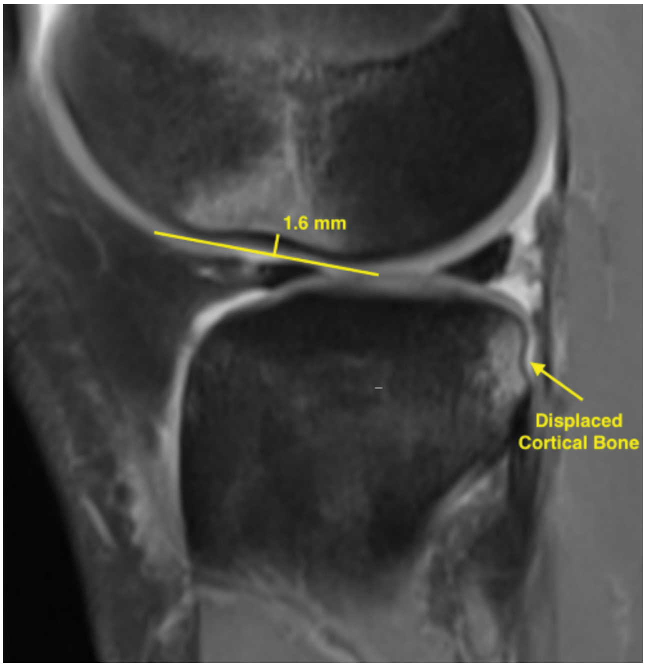

Figure 1. Sagittal image of magnetic resonance imaging scan demonstrating classification of lateral femoral condyle (>1.5 mm depth) and tibial plateau impaction fractures.

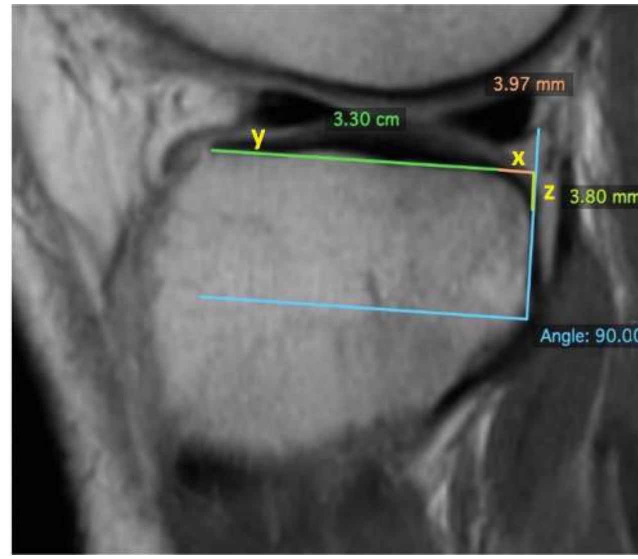

Figure 2. Measurement technique for tibial plateau impaction fracture. Sagittal image on magnetic resonance imaging scan demonstrating tibial plateau depth measurements in a control knee without an impaction fracture. Line *y* is drawn first along the subchondral bone from the anterior to posterior aspect 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 $x/(x + y)$.

articular distance was measured from anterior to posterior. This part of the method is the same as used by Wahl et al[21] to measure the tibial plateau anteroposterior length. A line perpendicular to this line was then drawn vertically and placed as a tangent line along the posterior-most aspect of the proximal lateral tibia. The distance from the posterior endpoint of the lateral tibial plateau articular surface to this vertical line was then recorded, denoted as the posterior articular marginal distance (Figure 2). Measurement of the posterior articular marginal distance was performed by 2 fellowship-trained orthopaedic surgeons (D.L.B., M.D.C.) in a subset of 30 patients and was shown to have excellent interrater reliability with an intraclass coefficient (ICC) of 0.939.

To use the posterior articular marginal distance as a proxy of articular surface loss, the above measurements were also made in a subset of 50 randomly selected control knees with ACL tear but without a lateral tibial impaction fracture. To allow for the assessment of possible differences between sexes, 25 male knees and 25 female knees were included in the control group. The posterior articular marginal percentage was calculated by dividing the posterior articular margin distance by the sum of the posterior articular margin distance and the lateral tibial plateau articular distance. This posterior articular marginal percentage calculated in control patients without impaction fracture was then averaged and subtracted from the posterior articular marginal percentages calculated for each knee with an impaction fracture to represent the percentage of articular surface depth bone loss (Figure 3).

The same sagittal image located at 50% of the width of the lateral tibial plateau was used to measure the height of the tibial plateau impaction fracture lesion at the anterior and posterior endpoints of the lesion, with measurement extending up to the modified Jakob and Amis line. The posterior height measurement was performed in the subset of control patients to allow for normalization as well. Finally, we measured the width of the tibial plateau and the width of the bony impaction lesion using axial MRI slices (Figure 3B).

Statistical Analysis

Descriptive statistics were used to evaluate the incidence of posterolateral tibial plateau and anterior or central lateral femoral condylar impaction fractures and bone bruising. In the subset of knees with a posterolateral tibial plateau fracture, additional descriptive statistics were used to describe the size and location of these lesions. Clinical characteristics for patients with posterolateral tibial plateau and anterior or central lateral femoral condylar impaction fractures and contusions were analyzed to assess for correlations with other knee structural injuries through use of chi-square testing for categorical variables and the Mann-Whitney *U* test for continuous variables with nonnormal distributions. All statistical analysis was performed through use of IBM SPSS Statistical Suite,

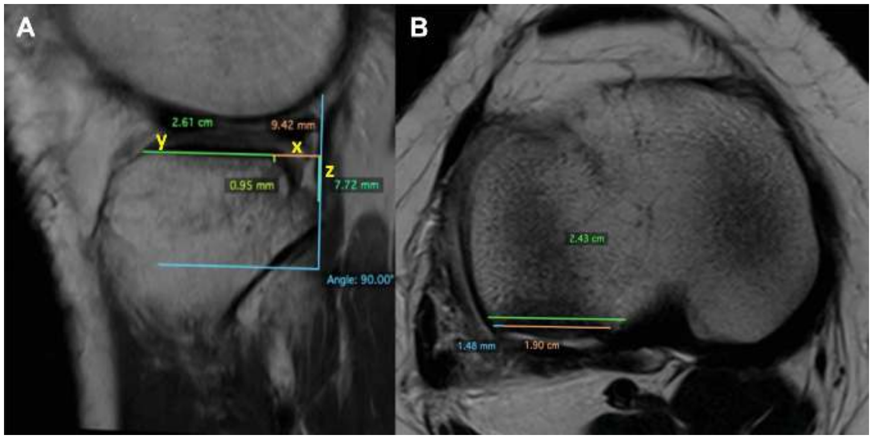

Figure 3. (A) Sagittal and (B) axial magnetic resonance imaging slices demonstrating (A) tibial plateau depth and (B) impaction lesion width measurements in a knee with an impaction fracture. Percentage of articular surface depth bone loss is calculated as $x/(x + y) - .099$ (control posterior articular marginal percentage).

version 25, and the alpha level was set for statistical significance at .05.

RESULTS

We identified 912 knees with primary ACL tears, and 825 knees (814 patients) had MRI scans available. A total of 805 patients were treated with ACL reconstruction and 20 patients were treated without surgery. The case series included 430 male (52.1%) and 395 female patients (47.9%). The mean ± SD body mass index of included patients was 24.4 ± 3.5. The mechanism of injury was noncontact for 80.1% of patients in the cohort. Displaced posterolateral tibial plateau impaction fractures were present in 407 knees (49.3%), and displaced anterior or central lateral femoral condylar impaction fractures were present in 214 knees (25.9%). A total of 512 knees (62.1%) had an impaction fracture of either the tibial plateau or the femoral condyle, whereas 109 knees (13.2%) had bipolar (both lateral femoral condyle and lateral tibial plateau) impaction fractures. Lateral tibial plateau bone bruising was present in 634 knees (76.8%), and lateral femoral condyle bone bruising was present in 407 knees (49.3%). A total of 654 (79.3%) knees had bruising of either the tibial plateau, the femoral condyle, or both, with only 385 of these knees having bipolar bruising (36.7%).

Patients with posterolateral tibial plateau impaction fractures were significantly older than patients without these fractures (40.4 vs 30.4 years; $P < .001$); however, lateral femoral condylar impaction fractures occurred in significantly younger patients (29.2 vs 37.5 years; $P < .001$). These age differences become even more substantial when we segregated isolated tibial plateau and femoral condyle impaction fractures from bipolar fractures (Table 1). Posterolateral tibial plateau impaction fractures occurred significantly more in female (54.2%) compared with male patients (44.8%) (chi-square value 7.3; $P = .007$), whereas no difference was found in rates of lateral femoral condylar or bipolar impaction fractures between sexes ($P = .38$ and .44, respectively). No association was found between body mass index and the occurrence of a posterolateral tibial plateau or lateral femoral condylar impaction fracture ($P = .67$). Both tibial and femoral impaction fractures occurred more frequently as a result of a noncontact injury mechanism (86.8% and 80.0%, respectively).

Table 2 provides the posterior articular margin distance and percentage and the posterior height of the lateral tibial plateau measured in the subset of control patients with an ACL tear but no impaction fracture. No difference was found between posterior articular margin percentage calculated in male controls compared with female controls ($P = .79$), thus justifying the use of a single correction factor for both male and female knees. The mean value for posterior articular marginal percentage measure from the controls was 9.9%, which was subsequently used as a correction factor when determining lateral tibial plateau bone loss in knees with impaction fractures.

Table 3 reports measurements of the lateral tibial plateau impaction lesions measured in this study. A total of 71 knees (8.6%) had a posterolateral tibial plateau impaction fracture with greater than 10% loss of lateral tibial plateau depth. Patients with greater than 10% loss of tibial plateau depth were significantly older than those without (50.6 vs 34.0 years; $P < .001$). There was a resultant subchondral bone step-off at the anterior aspect of the impaction fracture of 2 mm or greater in 30.0% of knees with impaction fractures. In the axial plane, the lesion was centered in the middle third of the lateral tibial plateau in 93.1% of all impaction lesions of the tibial plateau, with only 4.2% and 2.7% centered in the medial third and lateral third, respectively.

Associations between the presence of posterolateral tibial plateau and lateral femoral condyle impaction fractures or bone bruising and various meniscal injuries are shown in Table 4. Medial meniscal ramp lesions occurred more frequently in knees with tibial, femoral, and bipolar impaction fractures, as well as in knees with tibial or femoral

TABLE 1
Number and Age of Patients With Different Types of Impaction Fractures

	n (%)	Age, y		
		Mean ± SD	Minimum	Maximum
No fracture	313 (37.9)	32.7 ± 13.4	12.0	72.9
Tibial impaction	407 (49.3)	42.6 ± 12.8	12.9	73.6
Femoral impaction	214 (25.9)	23.8 ± 7.9	13.6	46.2
Bipolar impaction	110 (13.3)	34.6 ± 14.2	14.2	65.4
>10% tibial plateau depth loss	71 (8.6)	50.6 ± 11.9	18.3	73.6
Tibial bone bruise	633 (76.7)	35.6 ± 14.2	12.1	73.6
Femoral bone bruise	406 (49.2)	32.2 ± 14.1	12.1	72.9
Bipolar bone bruise	385 (46.7)	32.3 ± 14.2	12.1	72.9
Total	825	35.4 ± 14.2	11.2	73.6

TABLE 2
Posterolateral Tibial Plateau Measurements in Control Patient Group

	n	Mean ± SD
Posterior height, mm	50	4.0 ± 0.9
Posterior articular margin, mm	50	3.6 ± 0.7
Posterior articular marginal percentage		
Total	50	9.9 ± 1.8
Male	25	10.0 ± 2.0
Female	25	9.8 ± 1.6

TABLE 3
Fracture Lesion Measurements for Posterolateral Tibial Plateau Impaction

	Mean ± SD	Minimum	Maximum
Lateral tibial plateau depth bone loss, %	5.2 ± 5.1	0	24.1
Posterior height, mm	7.0 ± 2.2	2.1	15.3
Lesion articular step-off, mm	1.7 ± 2.3	0	9.0
Lesion width, mm	14.5 ± 5.0	3.2	30.1
Lesion axial midpoint (referenced from lateral-most aspect of posterior tibial plateau), %	49.9 ± 8.8	13.6	80.6

contusions, compared with patients without impaction fractures or bruising. The strongest significant association for ramp lesions occurred with femoral condyle impaction fractures, as ramp lesions were present in 27.1% of knees with femoral condyle impaction fractures compared with 15.6% of knees without (odds ratio, 2.0; 95% CI, 1.4-2.9; P = .001). Similarly, femoral condyle impaction fractures showed the strongest association with the incidence of lateral meniscal tears (66.7% vs 53.9%; odds ratio, 1.7; 95% CI, 1.2-2.4; P = .001), while bipolar impaction fractures and femoral contusions also had significant associations with lateral meniscal tears. Femoral impaction fractures and contusions showed significant correlations with lateral meniscus posterior root tears, but the largest differential in incidence percentage occurred in patients with greater than 10% lateral tibial plateau depth bone loss percentage (22.1% vs 12.0%; odds ratio, 2.1; 95% CI, 1.1-3.9; P = .02). When the bony morphologic features of the lateral tibial plateau impaction fracture lesion were compared in patients with and without lateral meniscus posterior root tears, a significantly greater bone loss percentage was noted in patients with root tears (7.2% vs 4.9%; P = .003); however, there was no difference in height or width of the lesion (P = .50 and .33, respectively).

Associations between the presence of posterolateral tibial plateau and lateral femoral condyle impaction fractures or bone bruising and associated ligament injuries are reported in Table 5. Combined ACL and posterolateral corner injuries had a very strong association with decreased incidence of tibial, femoral, and bipolar impaction fractures, as well as with femoral and tibial contusions ($P < .02$). Combined ACL and posterior cruciate ligament tears also showed a decreased incidence in the setting of either tibial impaction fractures or contusions ($P < .001$). However, combined ACL and medial collateral ligament tears had higher incidences in knees with lateral femoral contusions ($P < .02$).

DISCUSSION

The main finding of this study was the high rates of displaced impaction fractures of the posterolateral tibial plateau (49.3%) and the lateral femoral condyle (25.9%) in patients with primary ACL tears. Posterolateral tibial plateau impaction fractures were more likely to occur in older patients, whereas lateral femoral condylar impaction fractures occurred more often in younger patients. Although the clinical significance of these fractures is not yet known, this study demonstrated an association between these lesions and certain types of meniscal tears. Tibial, femoral, and bipolar impaction fractures were all associated with an increased risk of medial meniscal ramp tears, and femoral impaction fractures were associated with increased incidence of lateral meniscal tears and lateral meniscus posterior root tears ($P < .05$). Tibial impaction fractures resulting in greater than 10% loss of tibial plateau depth were also associated with an

TABLE 4
Chi-Square Associations Between Posterolateral Tibial Plateau and Lateral Femoral Condylar Impaction Fractures and Contusions With Various Meniscal Pathologic Conditions[a]

	Lateral Meniscal Tear		Lateral Meniscus Posterior Root Tear		Medial Meniscal Tear		Medial Meniscal Ramp Lesion		Medial Meniscus Posterior Root Tear	
	Incidence	*P*	Incidence	*P*	Incidence	*P*	Incidence	*P*	Incidence	*P*
Tibial impaction										
Not present	221/409 (54.0)	.06	51/406 (12.6)	.82	191/411 (46.5)	.28	66/410 (16.1)	**.05**	16/411 (3.9)	.65
Present	240/396 (60.6)		52/397 (13.1)		199/396 (50.3)		85/396 (21.5)		13/395 (3.3)	
Femoral impaction										
Not present	320/594 (53.9)	**.001**	66/592 (11.1)	**.03**	287/595 (48.2)	.98	93/595 (15.6)	**.001**	24/595 (4.0)	.27
Present	140/210 (66.7)		36/210 (17.1)		102/211 (48.3)		57/210 (27.1)		5/210 (2.4)	
Tibial contusion										
Not present	97/188 (51.6)	.08	16/186 (8.6)	.06	98/189 (51.9)	.27	23/189 (12.2)	**.01**	9/189 (4.8)	.33
Present	362/615 (58.9)		85/615 (13.8)		291/616 (47.2)		126/615 (20.5)		20/615 (3.3)	
Femoral contusion										
Not present	215/406 (53.0)	**.02**	37/405 (9.1)	**.003**	208/407 (51.1)	.11	63/407 (15.5)	**.02**	19/407 (4.7)	.10
Present	244/397 (61.5)		64/396 (16.2)		181/398 (45.5)		86/397 (21.7)		10/397 (2.5)	
Bipolar impaction										
Not present	388/696 (55.7)	**.03**	85/694 (12.2)	.22	336/698 (48.1)	.79	120/697 (17.2)	**.005**	26/698 (3.7)	.62
Present	73/107 (68.2)		18/109 (16.5)		54/109 (49.5)		31/109 (28.4)		3/108 (2.8)	
Tibial impaction >10%										
Not present	415/736 (56.4)	.07	88/735 (12.0)	**.02**	353/739 (47.8)	.29	136/738 (18.4)	.46	26/739 (3.5)	.69
Present	46/68 (67.6)		15/68 (22.1)		37/68 (54.4)		15/68 (22.1)		3/67 (4.5)	

[a]Incidence is expressed as n/N (%). Boldface indicates statistical significance.

increased incidence of lateral meniscus posterior root tears, with an incidence of 22.1% in this group.

Contusion of the lateral femoral condyle has been reported to occur in 20% to 60% of knees with ACL tears,[6] with this series reporting an incidence of 49.3%. Similarly, posterolateral tibial plateau impaction contusions have been reported to occur in 57% to 86% of knees with ACL tears,[3-5,14,16,23] with this series reporting an incidence of 76.8%. The anterior or central lateral femoral condyle and the posterior lateral tibial plateau have been noted to be the most common areas to sustain bone bruising in knees with noncontact ACL injury, as initial anterior translation of the tibia followed by a valgus moment and internal tibial translation will bring these areas of the knee joint together[14,22,24]; differences in the location of the lateral femoral condyle bone bruise in the anteroposterior direction are suggested to be attributable to differences in the amount of knee flexion occurring at time of injury.[14] Although overt posterolateral tibial plateau fractures visible on lateral radiographs associated with ACL tears have been previously reported,[8] no prior epidemiologic description of these fractures is available. This study provides detailed characterization of the incidence, size, and location of these impaction fractures. A more detailed characterization of the size and location of femoral condylar impaction fractures and corresponding lateral notch sign was previously reported by Hoffelner et al.[6] Although defining and characterizing these lesions are important initial steps, more information is necessary to determine the effect of these lesions on patient outcomes, both subjectively and objectively.

The potential effect of these impaction fractures on patient outcomes in the setting of ACL injury remains unknown. In a recent case-control study analyzing MRI measurements, Wahl et al[21] demonstrated that the tibial plateau articular depth was shorter in patients with ACL tears, which we theorize could mean that patients with bone loss resulting from impaction fracture could be at increased risk for ACL rerupture. Musahl et al[13] demonstrated that tibial plateau geometry can affect clinically detectable stability of the knee, with a decreased medial

TABLE 5
Chi-Square Associations Between Posterolateral Tibial Plateau and Lateral Femoral Condylar Impaction Fractures and Contusions With Various Ligamentous Injuries[a]

	Medial Collateral Ligament Injury		Fibular Collateral Ligament Injury		Posterolateral Corner Injury		Posterior Cruciate Ligament Injury	
	Incidence	*P*	Incidence	*P*	Incidence	*P*	Incidence	*P*
Tibial impaction								
Not present	86/418 (20.6)	.31	135/418 (32.3)	**.02**	37/418 (8.9)	**.001**	37/418 (8.6)	**.001**
Present	93/395 (23.5)		98/395 (24.8)		8/395 (2.0)		12/395 (3.0)	
Femoral impaction								
Not present	131/598 (21.9)	.87	166/598 (27.8)	.33	43/598 (7.2)	**.001**	40/598 (6.7)	.19
Present	48/214 (22.4)		67/214 (31.3)		2/214 (0.9)		9/214 (4.2)	
Tibial contusion								
Not present	37/190 (19.5)	.32	63/190 (33.2)	.13	32/190 (16.8)	**.001**	25/190 (13.2)	**.001**
Present	142/621 (22.9)		170/621 (27.4)		13/621 (2.1)		24/621 (3.9)	
Femoral contusion								
Not present	74/409 (18.1)	**.006**	117/409 (28.6)	.94	35/409 (8.6)	**.001**	24/409 (5.9)	.83
Present	105/402 (26.1)		116/402 (28.9)		10/402 (2.5)		25/402 (6.2)	
Bipolar impaction								
Not present	157/704 (22.3)	.62	202/704 (28.7)	.96	44/704 (6.3)	**.02**	46/704 (6.5)	.12
Present	22/109 (20.2)		31/109 (28.4)		1/109 (0.9)		3/109 (2.8)	
Tibial impaction >10%								
Not present	162/745 (21.7)	.54	223/745 (29.9)	**.008**	42/745 (5.6)	.67	46/745 (6.2)	.56
Present	17/68 (25.0)		10/68 (14.7)		3/68 (4.4)		3/68 (4.4)	

[a]Incidence is expressed as n/N (%). Boldface indicates statistical significance.

to lateral diameter of the lateral tibial plateau being associated with higher pivot-shift grade. Given that we observed a lateral tibial plateau depth bone loss percentage of greater than 10% in 8.6% of all patients in our primary ACL tear cohort, we found that altered lateral tibial plateau geometry is not that uncommon after a primary ACL tear. The current study did not include associations between clinical examination findings such as Lachman or pivot-shift grades in relation to the presence of lateral tibial plateau impaction fractures. Whether the tibial and femoral impaction fractures observed in the current case series have a clinically significant effect on postoperative knee stability and whether the presence of these lesions affects patient-reported outcomes require further investigation.

One of the key findings of this study that may have clinical utility is the association between tibial and femoral impaction fractures and contusions with associated meniscal and ligamentous pathologic changes. The associated increases in meniscal injuries, specifically with medial ramp lesions and lateral root tears, can heighten clinical suspicion for these meniscal injuries if the corresponding impaction fractures are found on imaging. Specifically, the presence of a femoral impaction fracture should increase concern for lateral meniscal tears, lateral meniscus posterior root tears, and medial meniscal ramp lesions, whereas a tibial impaction fracture affecting greater than 10% of the lateral tibial plateau depth should increase concern for a tear of the lateral meniscus posterior root. We observed associations with concomitant ligament tears with impaction fractures as well, with posterolateral tibial and lateral femoral impaction fractures and contusions associated with a decreased incidence of posterolateral corner tears and posterolateral tibial impaction fractures, and contusions with a decreased incidence of posterior cruciate ligament tears. We also found that lateral femoral condylar contusions should increase clinical suspicion for a medial collateral ligament tear. Prior studies have shown the same associations between increased lateral-sided contusions and increased incidence of lateral and medial meniscal tears; however, their analyses were limited to bone bruising only, with no investigation of more severe impaction injuries resulting in displacement of subchondral or cortical bone, which our data showed to have strong associations with certain meniscal and ligamentous injuries.[2,10,23]

This study is not without limitations. First, because preinjury MRI scans for the patients in this study were not available, the size of the tibial impaction fracture lesions were not measured by direct comparison of pre- and postinjury MRI scans. Instead, measurements were performed with the use of a correction factor based on the normal anatomic features of the lateral tibial plateau on MRI scans in a series of control patients. Although this method is reproducible, with an excellent ICC of 0.94 between 2 observers in this study, it provides an estimation of the actual impaction fracture lesion size rather than a direct measurement. Additionally, the greater than 10% tibial plateau depth categorization that we used for subanalysis of tibial plateau bone loss has no clinical basis. The 10% figure was chosen because it represents the mean percentage of measured bone loss plus 1 SD (mean 5.2%; SD, 5.1%). Furthermore, this amount of bone loss is similar to what has been considered significant bone loss based on previous models in the shoulder joint for anterior instability. Two previous studies have identified 13.5% and 21% of glenoid bone loss as significant contributors for increased risk of anterior shoulder instability in both clinical and biomechanical models, respectively.[7,15] Nonetheless, a limitation of the current study includes the lack of biomechanical and clinical validation of the amount of bone loss identified in the current sample of patients with ACL tear.

A second limitation was the use of MRI scans rather than computed tomography (CT) images to quantify bone injury. CT images would potentially provide more accurate diagnosis and measurement of impaction fractures since CT images better depict bone compared with MRI scans. However, MRI scans are more readily available to clinicians because these scans are usually part of the workup of ACL injuries, making the study more applicable. The MRI scans used in this study included both internal and external MRI studies, so both 1.5-T and 3.0-T studies were used. Overall, the inclusion of heterogeneous MRI protocols increases the generalizability of this study. There was no consistent time from injury when MRI was performed, which is a limitation, but the rates of bone bruising we observed were similar to those reported in the literature. To provide more consistency despite the inherent differences in the images that we used for measurement, we used a PACS viewer, which allowed for multiplanar reconstruction to ensure that measurements were made in the desired plane.

CONCLUSION

Displaced posterolateral tibial plateau impaction fractures occurred with a high incidence (49.3%) in patients with primary ACL tears and demonstrated an increased association with lateral meniscus posterior horn root tears as their size increased. Lateral femoral condylar impaction fractures occurred in 25.9% of patients with primary ACL tears and were associated with an increased incidence of lateral meniscal tears and medial meniscal ramp lesions.

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