UCSF
UC San Francisco Previously Published Works

Title
Bone Bruise Patterns Associated With Pediatric and Adult Anterior Cruciate Ligament Tears Are Different

Permalink
https://escholarship.org/uc/item/0x66m4xz

Journal
Arthroscopy Sports Medicine and Rehabilitation, 5(1)

ISSN
2666-061X

Authors
Orringer, Matthew
Lau, Justin
Feeley, Brian
et al.

Publication Date
2023-02-01

DOI
10.1016/j.asmr.2022.11.006

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

Original Article

Bone Bruise Patterns Associated With Pediatric and Adult Anterior Cruciate Ligament Tears Are Different

Matthew Orringer, Justin Lau, Brian Feeley, M.D., and Nirav Pandya, M.D.

Purpose: To describe differences in radiographic and magnetic resonance imaging (MRI) findings between adult and pediatric patients with known primary anterior cruciate ligament (ACL) injuries. **Methods:** We performed a retrospective analysis of surgical patients with a history of ACL tears treated at our institution over a 7-year period. Patients were divided into 2 cohorts based on age ($\leq$15 years and $\geq$21 years). Patients' radiographs and MRI studies were used to compare features including fracture incidence, bone bruise pattern, associated ligamentous injuries, and meniscal injuries between the 2 groups. Proportions of associated findings were analyzed using the 2-proportion z test. **Results:** Within our cohorts of 52 sex-matched pediatric and adult patients, we found that pediatric patients were more likely to have radiographic evidence of fracture ($P = .001$) and MRI evidence of lateral femoral condylar bone bruising ($P = .012$). Adult patients had higher rates of medial femoral condylar bruising ($P = .016$) and medial proximal tibial bruising ($P = .005$), as well as popliteal fibular ligament injuries ($P = .037$), identified on MRI. **Conclusions:** In this study, we identified differences in bone bruise patterns between pediatric and adult patients with primary ACL tears. Pediatric patients were more likely to have radiographic evidence of fracture and MRI evidence of lateral femoral condylar bone bruising. Adult patients were more likely to show medial femoral condylar and medial proximal tibial bone bruising, as well as popliteal fibular ligament injuries. **Level of Evidence:** Level IV, prognostic case series.

The anterior cruciate ligament (ACL) is crucial for knee stability. Along with the posterior cruciate ligament, the ACL forms a cross within the knee, preventing excessive anterior tibial translation while also assisting with rotational stability that results from varus or valgus stressors.[1] ACL tears are one of the most common ligament injuries both in the knee and in the United States.[2] The annual incidence of ACL tears in the United States is 68.6 per 100,000 person-years, resulting in about 100,000 to 200,000 ACL reconstructions per year and costing approximately $1.7 billion annually.[3,4] Tears are often due to sudden noncontact twisting motions or changes in direction that produce rotational forces capable of tearing the ligament.[5]

Magnetic resonance imaging (MRI) is the gold-standard imaging modality for the diagnosis of ACL pathology. The primary signs of an acute complete ACL tear are non-visualization of the ACL, discontinuity of the ligament, and increased T1 and T2 signal. Primary signs of acute partial tears include thickened ligaments with a T2-hyperintense signal with intact ACL fascicles.[6] Secondary signs of ACL injury include anterior tibial translation greater than 5 mm, as well as buckling of the posterior cruciate ligament.[6] In addition to these primary and secondary signs, the femoral notch volume can be measured on MRI because a decreased volume may be associated with ACL-deficient knees in adult and pediatric patients.[7-9] Imaging of ACL injuries in a pediatric population may share similar primary and secondary signs with imaging in an adult population; however, there are many differences that need to be considered in the diagnosis of a pediatric ACL injury versus an adult ACL injury. Pediatric ACL tears may be challenging to characterize owing to the difficulty in

From the School of Medicine, University of California, San Francisco, San Francisco, California, U.S.A. (M.O.); and Department of Orthopedic Surgery, University of California, San Francisco, San Francisco, California, U.S.A. (J.L., B.F., N.P.).

The authors report the following potential conflicts of interest or sources of funding: B.F. receives grants or pending grants from National Institutes of Health, OREF, and Orthofix; has a patent pending for a suture anchor; and owns stock or stock options in Bioniks and Kaliber AI, outside the submitted work. N.P. is a consultant for OrthoPediatrics, outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received July 23, 2022; accepted November 8, 2022.

Address correspondence to Matthew Orringer, UCSF School of Medicine, 500 Parnassus Ave, San Francisco, CA 94143, U.S.A. E-mail: matthew.orringer@ucsf.edu

© 2022 THE AUTHORS. Published by Elsevier Inc. on behalf of the Arthroscopy Association of North America. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

2666-061X/22933

https://doi.org/10.1016/j.asmr.2022.11.006

differentiating between an incompletely closed physis and an impaction fracture, as well as difficulty in visualizing the thinner pediatric ACL.[10] Furthermore, skeletally immature patients are more likely to have partial ACL tears and to have associated tibial spine avulsion fractures as compared with their skeletally mature counterparts.[10,11] In addition, skeletally mature patients may be more likely to exhibit a higher frequency of associated injuries.[11] Radiographs are commonly obtained during the evaluation of an ACL injury to determine the presence of fractures or associated risk factors such as an increased posterior tibial slope angle.[12]

Although many imaging studies have been conducted to identify primary and secondary signs of ACL injury, data are limited regarding the relative proportions of associated radiographic findings between adult and pediatric patients with ACL tears. Prior research has investigated radiographic differences in bipolar bone loss between adult and adolescent patients after anterior shoulder dislocation.[13] The purpose of this article was to describe differences in radiographic and MRI findings between adult and pediatric patients with known primary ACL injuries. We hypothesized that differences in associated injuries and imaging patterns would be observed between the adult and pediatric patients that may be due to differences in biomechanics or mechanisms of injury between the 2 groups.

Methods

Patient Selection

We performed a retrospective analysis of surgical patients with a history of ACL tears treated by 2 surgeons (N.P. and B.F.) at our institution over a 7-year period (2015-2021). Patients were divided into 2 cohorts based on age at the time of surgery: 15 years or younger (adolescent patients) and 21 years or older (adult patients). We used these age cutoffs to create a gap in years between the 2 groups and thus limit confounding that might occur by including pediatric patients who are skeletally mature and only a few months or years younger than the youngest adult patient in the adult cohort. All included patients had undergone an MRI study in the evaluation of their knee pathology. Only patients presenting for primary ACL tears were included in this study. All adult patients underwent arthroscopic ACL reconstruction with either hamstring autograft or posterior tibialis allograft.

Data Acquisition and Imaging Assessment

Institutional review board approval (No. 21-35878) was obtained before data acquisition began. A cohort of pediatric patients with primary ACL tears from 2015-2021 was first identified. Next, we identified the same number of sex-matched adult patients who had sought treatment for primary ACL tears at our institution. The electronic medical record and provider notes were used to gather demographic data including patient age at the time of surgery, time from injury to first MRI, and mechanism of injury.

Patients' preoperative radiographs were evaluated to determine the incidence of fractures. Fracture incidence was evaluated in 1 of 2 ways: (1) The report from a board-certified radiologist was compared with the imaging and cross-checked by one of the authors or (2) two of the authors (B.F. and N.P.) (each a board-certified sports medicine orthopaedic surgeon) evaluated the radiographs and cross-checked their findings. Any disagreements between findings were reviewed by all authors together until a consensus was reached. Patients' MRI findings were then evaluated using the same methodology. The following MRI characteristics were analyzed: bone bruise location, cartilage injury location, other (non-ACL) ligamentous injury, meniscal injury location, and characterization of ACL tear (partial vs complete).

Data Analysis

We compared the relative incidence of fractures identified on radiographs and the various associated MRI findings between the pediatric and adult cohorts by use of the 2-proportion z test. Statistical analyses were performed using Stata MP 16 analytical software (StataCorp, College Station, TX). The level of statistical significance was set at $P < .05$.

Results

Patient Demographic Characteristics

Our study cohort included 26 adult and 26 pediatric patients. Each cohort consisted of 17 male patients (65.4%) and 9 female patients (34.6%). The pediatric patients had a mean age of 11.8 years (standard deviation, 1.8 years; range, 8-15 years), whereas the adult patients had a mean age of 34.3 years (standard deviation, 8.1 years; range, 24-48 years). The time between injury and MRI was categorized as follows: unknown, 0 to 2 weeks, 2 to 4 weeks, 4 to 8 weeks, or greater than 8 weeks. For both patient cohorts, the most common interval was 0 to 2 weeks. There were no statistically significant differences in time to MRI between the pediatric and adult cohorts ($P \geq .224$). The most common mechanisms of injury included skiing and playing soccer. However, most pediatric and adult patients were injured while participating in "other" activities. There was not another specific activity that led to more than 2 patient injuries. There were no statistically significant differences between the 2 groups regarding which activities patients were participating in at the time of injury ($P \geq .731$). These data are summarized in Table 1.

Table 1. Patient Demographic Characteristics

Variable	Pediatric Patients	Adult Patients	*P* Value
Sex			
Male	17 (65.4)	17 (65.4)	
Female	9 (34.6)	9 (34.6)	
Age on date of surgery, yr			
Mean (SD)	11.8 (1.8)	34.3 (8.1)	
Range	8-15	24-48	
Time to MRI			
Unknown	3 (11.5)	3 (11.5)	>.999
0-2 wk	12 (46.2)	15 (57.7)	.407
2-4 wk	5 (19.2)	3 (11.5)	.441
4-8 wk	5 (19.2)	2 (7.7)	.224
>8 wk	1 (3.8)	3 (11.5)	.296
Mechanism of injury			
Skiing	5 (19.2)	6 (23.1)	.731
Soccer	5 (19.2)	5 (19.2)	>.999
Other	16 (61.5)	15 (57.7)	.780

NOTE. Data are presented as number (percentage) unless otherwise indicated.

MRI, magnetic resonance imaging; SD, standard deviation.

Table 2. Radiographic Findings

Radiographic Findings	Pediatric Patients (n = 16)	Adult Patients (n = 25)	*P* Value
Evidence of fracture	4 (25.0)*	0	.001†

NOTE. Data are presented as number (percentage).

*Fracture locations included the lateral proximal tibia, patella, notch, and inferior pole of the patella with tibial tuberosity involvement.

†Statistically significant ($P < .05$).

Radiographic Findings

Preoperative radiographs were obtained for 16 of the 26 pediatric patients. Of these pediatric patients, 4 (25%) had evidence of fracture on radiographs, consisting of a lateral proximal tibial avulsion fracture (1), patellar avulsion fracture (1), incomplete patellar fracture (1), and notch avulsion fracture (1). Of the 25 adult patients for whom preoperative radiographs were obtained, none had radiographic evidence of fracture. Pediatric patients were significantly more likely to have radiographic evidence of fracture ($P = .001$). Table 2 summarizes these data.

MRI Findings

Within our cohort of pediatric patients, 20 of 26 (76.9%) had MRI evidence of bone bruising as compared with 23 of 26 adults (88.5%) ($P = .269$). We found statistically significant differences in the location of bone bruising between the 2 groups. Pediatric patients were more likely to have bone bruising noted in the lateral femoral condyle (LFC) (73.1%) as compared with adults (38.5%) ($P = .012$) (Fig 1). Conversely, adults were more likely to have bruising of the medial femoral condyle (MFC) (46.2% vs 15.4%, $P = .016$) and medial proximal tibia (34.6% vs 3.8%, $P = .005$) (Fig 2). We did not observe statistically significant differences in the proportions of patients with bone bruising in the lateral proximal tibia, fibular head, or patella.

Next, we examined the relative proportions of MRI evidence of articular cartilage injury between the 2 groups. Cartilage injuries were observed in 5 adult patients (19.2%) versus 2 pediatric patients (7.7%). Of the adult patients, 2 had LFC lesions, 2 had MFC lesions, and 1 had a lateral proximal tibial defect. The pediatric cartilage injuries included 1 injury to the LFC and 1 injury to the lateral patella. There was not a statistically significant difference between the 2 groups regarding the overall rate of cartilage injury ($P = .224$). Furthermore, we did not find statistically significant differences in cartilage injury location distribution between the adult and pediatric patients.

We additionally examined non-ACL ligamentous injury in our cohort of patients. Of the 26 pediatric patients, 12 (46.2%) had an associated ligamentous injury, whereas 13 adults (50%) had a non-ACL ligamentous injury ($P = .784$). We found that each group included 8 patients with medial collateral ligament pathology ($P > .999$). Lateral collateral ligament injury occurred in 6 adults (23.1%) versus 2 pediatric patients (7.7%); however, this result was not statistically significant ($P = .124$). Adult patients (15.4%) were more likely to have MRI evidence of popliteal fibular ligament (PFL) injury as compared with pediatric patients (0%) ($P = .037$). Of the 4 adults with PFL injuries, 3 had partial tears whereas 1 had a complete tear.

Meniscal injuries were common in our cohorts of pediatric (57.7%) and adult (69.2%) patients ($P = .389$). However, we did not find statistically significant differences in the relative proportions of patients with isolated medial or lateral meniscal injury or those with both medial and lateral pathologies.

Finally, although all patients in our cohort were ultimately treated surgically, we found that 11.5% of pediatric patients had partial ACL tears as compared with 0% of adult patients. However, this result was not statistically significant ($P = .075$). These data are summarized in Table 3.

Discussion

In this study, we identified differences in bone bruise patterns between pediatric and adult patients with primary ACL tears. We found that pediatric patients were more likely to have radiographic evidence of fracture as compared with adult patients ($P = .001$). This finding is consistent with the findings of Prince et al.,[11] who showed that skeletally immature patients

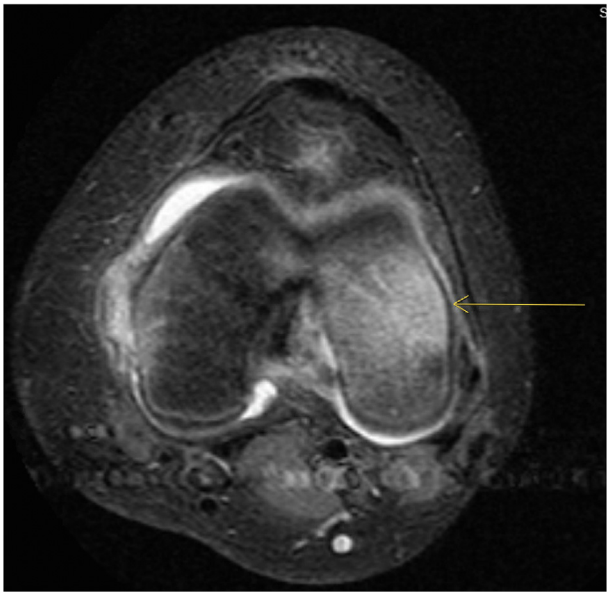

Fig 1. Axial fast spin echo magnetic resonance image of left knee in 10-year-old girl with lateral femoral condylar bone marrow edema (arrow).

were more likely to exhibit tibial spine avulsion fractures on MRI as compared with their more skeletally mature counterparts. We found that 25% of patients in our pediatric cohort had radiographic evidence of fracture. Prince et al. found a tibial spine avulsion fracture rate of 26% among skeletally immature patients. Of the 4 patients in our cohort with evidence of fracture, only 1 had a tibial spine avulsion fracture (6.25% overall). Because our study included analysis of only 16 pediatric radiographs, it is possible that our study is underpowered to detect overall rates of tibial spine fractures specifically. Given that fractures related to the patella occurred in 2 of our patients, it is possible that these patients experienced patellofemoral instability events in addition to their ACL injuries.

Although we found no significant difference in the overall rate of bony contusions between pediatric and adult patients, we did find statistically significant differences in the location of bony contusions. Pediatric patients were more likely than adults to have LFC bruises ($P = .012$), whereas adults were more likely than pediatric patients to have MFC bruising ($P = .016$) and medial proximal tibial bruising ($P = .005$). Prince et al.[11] found that the LFC and posterolateral tibial plateau were the most common locations of bony contusions in patients with ACL pathology among both skeletally immature and skeletally mature patients. Moreover, D'Hooghe et al.[14] studied 19 professional soccer players with ACL tears and found that although 84% had LFC bruising, none had MFC bruising patterns. Similarly, Moran et al.[15] found that LFC bone bruises were more common than MFC bruises (67% vs 33%) and the lateral tibial plateau was more frequently affected than the medial tibial plateau (65% vs 35%). Within our cohort of pediatric patients, we also observed greater rates of LFC bruising than MFC bruising (73.1% vs 15.4%) and more frequent lateral proximal tibial bruising than medial proximal tibial bruising (69.2% vs 3.8%). These findings are consistent with the results of prior research. However, the 26 adult patients studied exhibited higher rates of MFC bruising than LFC bruising (46.2% vs 38.5%) and showed higher rates of MFC bruising ($P = .016$) and medial proximal tibial bruising ($P = .005$) than the pediatric cohort. Viskontas et al.[16] found that although LFC bruising was more commonly associated with ACL tears than MFC bruising, medial-compartment bone bruising was especially common among patients with noncontact injuries. Furthermore, they found that medial-compartment bruising was associated with sagittal-plane loading more than valgus loading among subjects with noncontact injuries. Kaplan et al.[17] found that medial-compartment bruising was associated with a contrecoup mechanism of injury. Although we found that the adult and pediatric patients were participating in similar activities at the time of the ACL tear, our chart review did not allow for more granular analysis of noncontact versus contact mechanisms of injury. Thus, it is possible that the increased rates of medial-compartment bone bruising among the adult patients are related to either noncontact sagittal-plane loading or contrecoup or compensatory varus alignment occurring at greater rates within the adult cohort.

Fig 2. Coronal fat-suppressed proton density magnetic resonance image of left knee in 27-year-old man with medial femoral condylar bone marrow edema (arrow).

Table 3. MRI Findings

MRI Findings	Pediatric Patients	Adult Patients	*P* Value
Bone bruising*			
Any	20 (76.9)	23 (88.5)	.269
Lateral femoral condyle	19 (73.1)	10 (38.5)	.012†
Medial femoral condyle	4 (15.4)	12 (46.2)	.016†
Lateral proximal tibia	18 (69.2)	16 (61.5)	.560
Medial proximal tibia	1 (3.8)	9 (34.6)	.005†
Fibular head	3 (11.5)	2 (7.7)	.642
Inferior patellar pole	0	1 (3.8)	.316
Cartilage injury			
Any	2 (7.7)	5 (19.2)	.224
Lateral femoral condyle	1 (3.8)	2 (7.7)	.546
Lateral patella	1 (3.8)	0	.316
Medial femoral condyle	0	2 (7.7)	.149
Lateral tibial plateau	0	1 (3.8)	.316
Other ligamentous injury*			
Any	12 (46.2)	13 (50)	.784
Medial collateral ligament	8 (30.8)	8 (30.8)	>.999
Lateral collateral ligament	2 (7.7)	6 (23.1)	.124
Popliteus	1 (3.8)	0	.316
Meniscopopliteal fascicle	2 (7.7)	2 (7.7)	>.999
Meniscocapsular ligament	1 (3.8)	0	.316
Meniscotibial ligament	1 (3.8)	0	.316
Medial popliteal femoral ligament	1 (3.8)	0	.316
Popliteal fibular ligament	0	4 (15.4)	.037†
Medial patellofemoral ligament	0	2 (7.7)	.149
Posterior cruciate ligament	0	1 (3.8)	.316
Arcuate ligament	0	1 (3.8)	.316
Meniscal injury			
Any	15 (57.7)	18 (69.2)	.389
Isolated medial meniscus	5 (19.2)	7 (26.9)	.510
Isolated lateral meniscus	4 (15.4)	2 (7.7)	.385
Medial meniscus and lateral meniscus	6 (23.1)	9 (34.6)	.360
Anterior cruciate ligament tear			
Partial	3 (11.5)	0	.075
Complete	23 (88.5)	26 (100)	.075

NOTE. Data are presented as number (percentage).
MRI, magnetic resonance imaging.
*Some patients had more than 1 ligamentous injury or bone bruise location.
†Statistically significant ($P < .05$).

Future research is warranted to better characterize the cause of these results.

We found similar overall rates of cartilage injury between adult and pediatric patients. In addition, we found that overall, other ligamentous injury rates were similar between the adult and pediatric cohorts. Medial collateral ligament injuries occurred in 8 adult patients and 8 pediatric patients (30.8% in each cohort). Adults were more likely to have lateral collateral ligament injuries (23.1% vs 7.7%); however, this result was not statistically significant ($P = .124$). We did find that adult patients were more likely to have radiographic evidence of PFL pathology as compared with pediatric patients ($P = .037$). Posterolateral corner injuries, such as injury to the PFL, rarely occur in isolation and are often associated with ACL pathology.[18] Among 180 patients with acute knee pain who underwent MRI, 20% of patients had PFL injuries, and this was strongly associated with ACL rupture.[19] Because the PFL contributes to external rotation stability, it is possible that the adult patients were more likely to experience ACL tears as a result of excessive external rotatory forces. It is also possible that the PFL, similarly to the ACL, is thinner in pediatric patients, and thus, it is more difficult to identify pathology on MRI. Further research is necessary to better understand the forces that contribute to PFL tears, especially in the context of ACL pathology. Additional research is also needed to better understand why adult patients may have higher rates of radiographic PFL pathology associated with ACL tears.

We did not find statistically significant differences in the rates of overall meniscal injury between pediatric and adult patients (57.7% and 69.2%, respectively; $P = .389$). These rates of ACL-associated meniscal injury are in line with the rates of 61% and 63% observed in prior research.[20,21] It is interesting to note that adult patients had more isolated medial meniscal injuries (26.9% vs 19.2%) and fewer isolated lateral meniscal injuries (7.7% vs 15.4%); however, these results were not statistically significant. Because adult patients in our cohort also had increased radiographic evidence of medial-compartment bone bruising ($P = .016$ for MFC bruising and $P = .005$ for medial proximal tibia bruising), it is possible that medial knee damage globally was more common among our skeletally mature patients, although our sample size may have been underpowered to detect such differences in meniscal injury rates. Future work is needed to better elucidate these findings.

Finally, we found that 11.5% of pediatric patients had partial ACL tears as compared with 0% of adult patients ($P = .075$). Prince et al.[11] have shown that partial ACL tears are more common among skeletally immature patients; thus, our results are in line with this prior research, although our data only approach the level of statistical significance.

Limitations

There are certain limitations related to the design of this study. First, the modest sample size of the study may not be sufficient to detect differences between the pediatric and adult populations. Furthermore, skiing and soccer were the most common activities associated with an ACL tear in our study population. Our findings are specific to this study population, and our patients may differ from those in other regions where different sports are more popular. Furthermore, there may have been patients who were skeletally mature within the pediatric group, which may influence the injury patterns observed. The time from initial injury to imaging was unknown in a proportion of our patients, and certain pediatric patients lacked radiographs. This may impact bone bruising patterns as well as the identification of secondary injuries, which is a limitation of the study design. Similarly, it is possible that certain patients, especially within the adult cohort, had pre-existing injuries prior to ACL injury, such as articular cartilage defects. In addition, there are inherent limitations in characterizing rates of injury based on the interpretation of radiographic studies. For example, there are likely differences between physicians regarding what degree of bone marrow edema seen on MRI is interpreted as a bone bruise. We attempted to mitigate this phenomenon either by having at least 1 study author cross-check the images and radiology reports or by having 2 authors evaluate the imaging findings to increase validity. However, there is still potential for error and variation in the imaging interpretations. Additionally, although we controlled for the proportions of adult patients and pediatric patients who were male or female, there may be other factors that were not available in the electronic medical record that could influence the results of this study, such as a patient's body mass index. Finally, our study focused on patients who underwent operative treatment of symptomatic ACL tears. However, there may be radiographic findings associated with both adult and pediatric patients who choose nonoperative management.

Conclusions

In this study, we identified differences in bone bruise patterns between pediatric and adult patients with primary ACL tears. Pediatric patients were more likely to have radiographic evidence of fracture and MRI evidence of LFC bone bruising. Adult patients were more likely to show MFC and medial proximal tibial bone bruising, as well as PFL injuries.

References

1. Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Ménétrey J. Anatomy of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc* 2006;14:204-213.
2. Siegel L, Vandenakker-Albanese C, Siegel D. Anterior cruciate ligament injuries: Anatomy, physiology, biomechanics, and management. *Clin J Sport Med* 2012;22:349-355.
3. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: A 21-year population-based study. *Am J Sports Med* 2016;44:1502-1507.
4. Raines BT, Naclerio E, Sherman SL. Management of anterior cruciate ligament injury: What's in and what's out? *Indian J Orthop* 2017;51:563-575.
5. Boden BP, Dean GS, Feagin JA Jr, Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics* 2000;23:573-578.
6. Kam CK, Chee DW, Peh WC. Magnetic resonance imaging of cruciate ligament injuries of the knee. *Can Assoc Radiol J* 2010;61:80-89.
7. Zhang C, Xie G, Fang Z, Zhang X, Huangfu X, Zhao J. Assessment of relationship between three dimensional femoral notch volume and anterior cruciate ligament injury in Chinese Han adults: A retrospective MRI study. *Int Orthop* 2019;43:1231-1237.
8. Wratten CJ, Tetsworth K, Hohmann E. Three-dimensional femoral notch volume in anterior cruciate ligament-deficient versus anterior cruciate ligament-intact patients: A matched case-control study with inter-gender comparison. *Arthroscopy* 2015;31:1117-1122.
9. Swami VG, Mabee M, Hui C, Jaremko JL. Three-dimensional intercondylar notch volumes in a skeletally immature pediatric population: A magnetic resonance imaging-based anatomic comparison of knees with torn and intact anterior cruciate ligaments. *Arthroscopy* 2013;29:1954-1962.
10. Jaremko JL, Guenther ZD, Jans LB, Macmahon PJ. Spectrum of injuries associated with paediatric ACL tears: An MRI pictorial review. *Insights Imaging* 2013;4:273-285.
11. Prince JS, Laor T, Bean JA. MRI of anterior cruciate ligament injuries and associated findings in the pediatric

knee: Changes with skeletal maturation. *AJR Am J Roentgenol* 2005;185:756-762.
12. Haase L, Magister S, Nelson G, et al. Ipsilateral ACL injured patients with Segond fractures demonstrate increased posterior tibial slope. *Knee* 2022;38:76-81.
13. Lau BC, Conway D, Curran PF, Feeley BT, Pandya NK. Bipolar bone loss in patients with anterior shoulder dislocation: A comparison of adolescents versus adult patients. *Arthroscopy* 2017;33:1755-1761.
14. D'Hooghe P, Grassi A, Villa FD, et al. The injury mechanism correlation between MRI and video-analysis in professional football players with an acute ACL knee injury reveals consistent bone bruise patterns [published online June 13, 2022]. *Knee Surg Sports Traumatol Arthrosc*. https://doi.org/10.1007/s00167-022-07002-6.
15. Moran J, Katz LD, Schneble CA, et al. A novel MRI mapping technique for evaluating bone bruising patterns associated with noncontact ACL ruptures. *Orthop J Sports Med* 2022;10:23259671221088936.
16. Viskontas DG, Giuffre BM, Duggal N, Graham D, Parker D, Coolican M. Bone bruises associated with ACL rupture: Correlation with injury mechanism. *Am J Sports Med* 2008;36:927-933.
17. Kaplan PA, Gehl RH, Dussault RG, Anderson MW, Diduch DR. Bone contusions of the posterior lip of the medial tibial plateau (contrecoup injury) and associated internal derangements of the knee at MR imaging. *Radiology* 1999;211:747-753.
18. LaPrade RF, Wentorf FA, Fritts H, Gundry C, Hightower CD. A prospective magnetic resonance imaging study of the incidence of posterolateral and multiple ligament injuries in acute knee injuries presenting with a hemarthrosis. *Arthroscopy* 2007;23:1341-1347.
19. McKean D, Yoong P, Yanny S, et al. The popliteal fibular ligament in acute knee trauma: Patterns of injury on MR imaging. *Skeletal Radiol* 2015;44:1413-1419.
20. Michalitsis S, Vlychou M, Malizos KN, Thriskos P, Hantes ME. Meniscal and articular cartilage lesions in the anterior cruciate ligament-deficient knee: Correlation between time from injury and knee scores. *Knee Surg Sports Traumatol Arthrosc* 2015;23:232-239.
21. Şeyma Torgutalp Ş, Dönmez G, Korkusuz F. Incidence rates of injuries associated with anterior cruciate ligament tear diagnosed by magnetic resonance imaging: A retrospective cohort study. *Turk J Sports Med* 2020;56:33-37.