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Impaction Fractures of the Lateral Femoral Condyle Related to Anterior Cruciate Ligament Injury: A Scoping Review Concerning Diagnosis, Prevalence, Clinical Importance, and Management

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Background: During pivot-shift anterior cruciate ligament (ACL) injury, bone bruises or impaction fractures of the lateral femoral condyle (LFC-IF) may occur due to impaction between the posterior part of the lateral tibial plateau and anterocentral part of the LFC. The purpose of the study was to systematically review the literature concerning the diagnosis, prevalence, clinical importance, and management of LFC-IF occurring during ACL injuries.

Methods: Included were studies concerning impaction fractures of the anterocentral part of the LFC occurring during ACL injuries. Studies concerning only bone bruises or cartilage lesions, without subchondral bone impaction, were not included. A search was performed in Medline and Scopus databases, with final search in May 2022. A secondary search was conducted within the bibliographies of included articles and using "Cited In" option. Two authors independently extracted data in three domains: study design, LFC-IF characteristics, and LFC-IF importance and management.

Results: A total of 35 studies were included for review with several studies reporting on multiple domains. Summarily, 31 studies were on the diagnosis and prevalence, 19 studies reported on the clinical importance, and 4 studies reported on the management of LFC-IF.

Conclusions: A LFC-IF occurs due to the pivot-shift mechanism of ACL injury. Its radiological feature is defined as an impaction of terminal sulcus deeper than 1 mm and is present in up to 52% of patients with a torn ACL. An LFC-IF causes injury to the cartilage, probably leads to its progressive degeneration, and is significantly associated with an increased risk of a lateral meniscus injury. A large LFC-IF might be associated with greater rotational knee instability. Although several techniques of LFC-IF treatment were proposed, none of them has been evaluated on a large cohort of patients to date.

Keywords: *Femoral fractures, Distal, Impaction fracture, Anterior cruciate ligament injuries, Meniscus, Cartilage*

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The anterior cruciate ligament (ACL) is a primary stabilizer of anterior and rotational stability of the knee.[1,2] An ACL tear is one of the most common sports injuries[1,3,4] with the annual prevalence as high as 81 per 100,000.[5] Different mechanisms of ACL injury exist, associated with different bony injury patterns.[6-9] One of these mechanisms is the combination of anterior translation and internal rotation of the tibia, commonly referred to as a pivot-shift mechanism.[1,8-11] It results in an impaction between the posterior part of the lateral tibial plateau (LTP) and the anterocentral part of the lateral femoral condyle (LFC), usually in the area of the terminal sulcus (TS).[1,7-12] The result of such impaction may be cartilage injury, subcortical bone bruise, or even a so called "impaction fracture" or "depression fracture." The difference between bone bruises and impaction fractures was considered that in bone bruises there is no change in the subchondral bone shape, while in an impaction fracture, there is an observable depression of cartilage resulting from the subchondral bone impaction (Fig. 1).[9,10,13] Due to a similar etiology, LFC impaction fractures (LFC-IF) were compared to Hill-Sachs lesions occurring during anterior shoulder displacement.[3,9,11,14-17]

While in the literature there are many original studies and reviews concerning bone bruises of the LFC related with ACL injury,[18-20] LFC-IF have been less extensively investigated.[9] To the best of the authors' knowledge, no literature review has been performed to date on this topic. The prevalence of LFC-IF in ACL injuries has been reported to be as high as 51%.[21] Furthermore, an increasing number of original studies published in the last few years, such as the studies of Dimitriou et al.,[21] published in KSSTA 2020 or Bernholt et al.[9] and Lucidi et al.,[22] published in American Journal of Sports Medicine in 2020 and 2021, reported an increase of the pivot-shift phenomenon in knees with LFC-IF, underlining the possible importance of LFC-IF in regards to ACL reconstruction functional outcomes and the need for revision. Therefore, it was considered important to provide clinicians with overview of the rising body of the literature on this topic. The aim of this study was to systematically review the literature concerning diagnosis, prevalence, clinical importance, and management of LFC-IF occurring during ACL injuries. As this was a scoping review of the literature, there was no pre-defined hypothesis as to the review results.

METHODS

This scoping review was conducted in accordance with an extension of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for scoping reviews (Fig. 2).[23]

Study Eligibility

The inclusion and exclusion criteria listed in Table 1 were deemed for study eligibility. There were no restrictions regarding the date of publication, language, or study design.

Literature Search

The search was performed in the Medline and Scopus databases, with the final search performed in February 2022. The secondary search was conducted within the bibliographies of included articles and using "Cited In" option. The following search entry was used: ((bone [Title/Abstract]) OR (bony [Title/Abstract]) OR (osseous [Title/Abstract]))

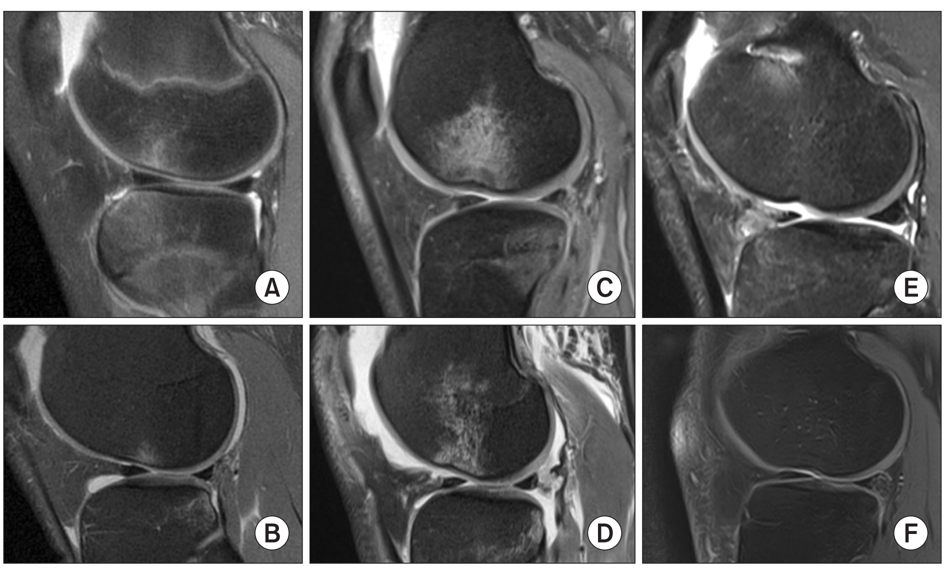

Fig. 1. Difference between lateral femoral condyle bone bruise and lateral femoral condyle impaction fracture (LFC-IF). (A, B) Two different patients with bone bruise of LFC with no change in the subchondral bone shape. (C, D) Two different patients with LFC-IF and bone bruise due to impaction force, acutely after anterior cruciate ligament tear. Depression of cartilage resulting from subchondral bone impaction can be observed. (E, F) Two different patients with LFC-IF in chronic setting. Bone bruise is no more visible; however, depression of cartilage and subchondral bone impaction can still be seen.

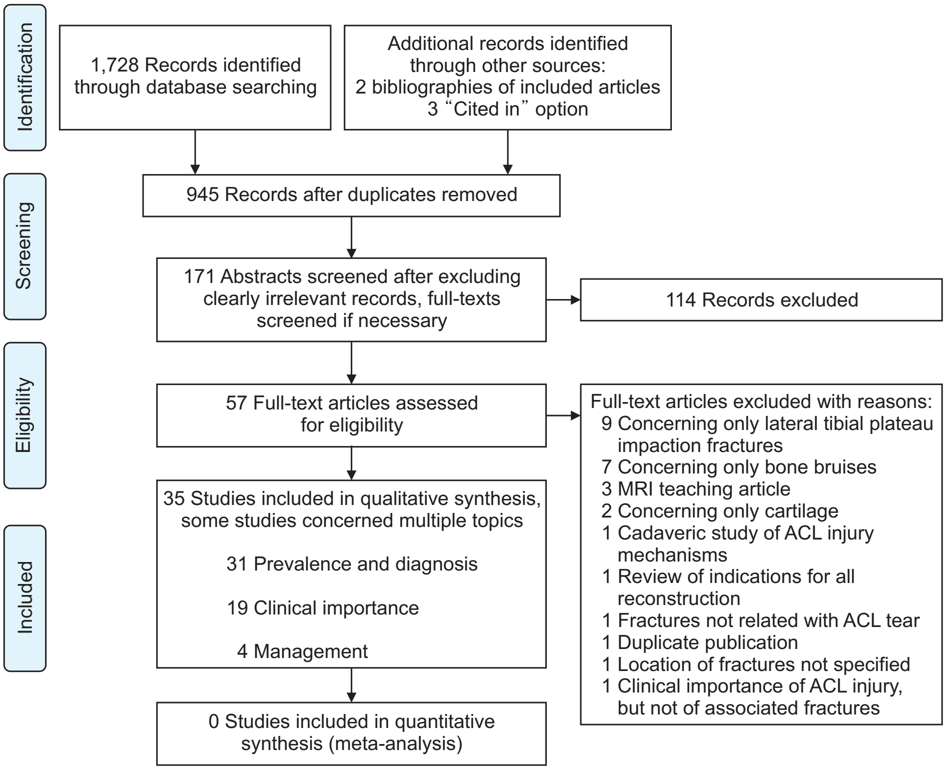

Fig. 2. Flowchart of study selection for lateral femoral condyle impaction fractures. MRI: magnetic resonance imaging, ACL: anterior cruciate ligament.

Table 1. Inclusion and Exclusion Criteria for Study Eligibility

Inclusion criteria	Exclusion criteria
Studies concerning impaction fractures of the anterocentral part of LFC occurring during ACL injuries	Studies concerning fractures of LFC not associated with ACL injury Displaced fractures (other than impaction) Studies concerning fractures of other regions of the knee, even those associated with ACL injury Studies concerning only bone bruises or cartilage lesions

LFC: lateral femoral condyle, ACL: anterior cruciate ligament.

AND ((anterior cruciate ligament [Title/Abstract]) OR (ACL [Title/Abstract])) AND ((injuries [Title/Abstract]) OR (fractures [Title/Abstract]) OR (impaction [Title/Abstract]) OR (bone bruises [Title/Abstract]) OR (bone marrow [Title/Abstract]) OR (lateral femoral notch [Title/Abstract]) OR (lateral femoral sulcus [Title/Abstract]) OR (sulcus terminalis [Title/Abstract]) OR (terminal sulcus [Title/Abstract])).

Study Selection

The study selection was performed in the stepwise manner according to the PRISMA flowchart (Fig. 2). The assessment was performed independently by two authors (MM and KR) accordingly to the inclusion and exclusion criteria presented in Table 1, and disagreements were resolved by consensus.

Data Charting Process

From the included studies, two authors (MM and KR) independently extracted data in three domains: study design, LFC-IF characteristics, and LFC-IF importance and management, as presented in Table 2. In case of disagreements, they were resolved by the senior author (KM). The charted data are summarized in the subsections of Results.

RESULTS

Study Selection

A total of 35 studies were included for review with several studies reporting on multiple domains. Summarily, 31 studies were on the diagnosis and prevalence, 19 reported on clinical importance, and 4 studies reported on management. The process of study selection is presented in Fig. 2.

Table 2. Data Charting Process in Three Domains: Study Design, LFC-IF Characteristics, and LFC-IF Importance and Management

Study design	LFC-IF characteristics	LFC-IF importance and management
Number and demographics of patients with ACL injury	Mean depth of LFC-IF vs. TS in healthy controls	The influence of LFC-IF on knee function and stability
Whether the ACL tear was partial or complete	Percentage of patients with LFC-IF	Concomitant injuries
Modality of imaging examination (X-ray/MRI)	Utilized diagnostic signs	Risk of developing osteoarthritis
Time from injury to imaging	Diagnostic characteristics of utilized signs	Treatment methods and their outcomes

LFC-IF: lateral femoral condyle impaction fracture, ACL: anterior cruciate ligament, TS: terminal sulcus, MRI: magnetic resonance imaging.

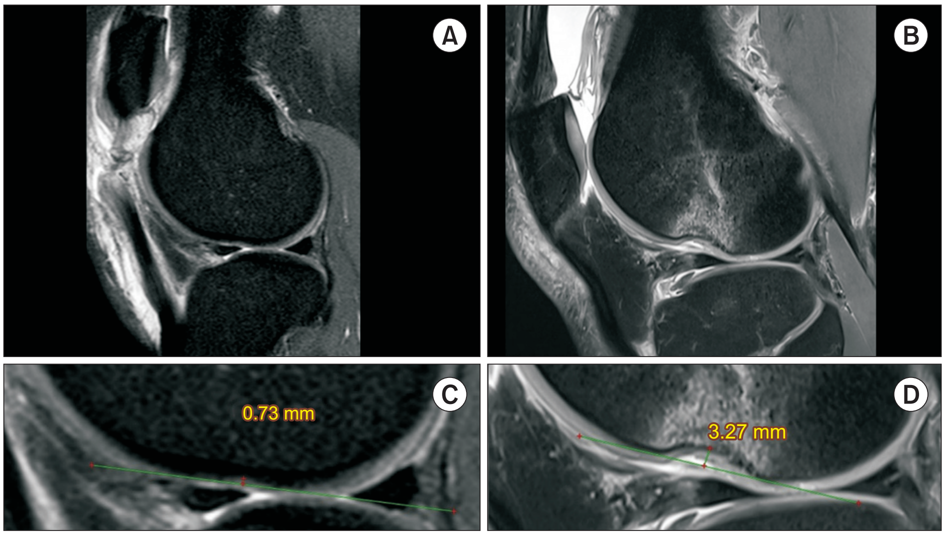

Fig. 3. Comparison of anatomical terminal sulcus (TS) and lateral femoral condyle impaction fracture. (A) Anatomical TS in the patient who had magnetic resonance imaging performed due to patellar ligament rupture. (B) Lateral femoral condyle impaction fracture (LFC-IF) in the patient after anterior cruciate ligament tear. (C) Measurement of TS depth. (D) Measurement of LFC-IF depth.

Table 3. The Prevalence of the LFNS with an ACL Tear on Plain Radiographs or MRI According to the LFNS Cutoff Value in Included Studies

LFNS cutoff value	On plain radiographs		On MRI scans	
	Prevalence of LFNS (%)	Study	Prevalence of LFNS (%)	Study
0.5 mm	52.0	Dimitriou et al. (2020)[21]	NA	NA
1.0 mm	14.8–36.9	Cobby et al. (1992)[24] Nakauchi et al. (2000)[25] Lodewijks et al. (2019)[26]	28.9–48	Frobell et al. (2008)[5] Behzadi et al. (2018)[4] Lucidi et al. (2021)[22]
1.5 mm	0–15.4	Warren et al. (1988)[27] Cobby et al. (1992)[24] Jones et al. (1993)[28] Hoffelner et al. (2015)[8] Lodewijks et al. (2019)[26]	11.8–41.6	Yeung et al. (1998)[29] Chang et al. (2014)[30] Hoffelner et al. (2015)[8] Celikyay et al. (2020)[31]
2.0 mm	3.2–50.8	Yu et al. (1995)[32] Garth et al. (2000)[33] Sonnery-Cottet et al. (2015)[2] Herbst et al. (2015)[3] Kanakamedala et al. (2018)[11] Marot et al. (2021)[34]	9.4–21.8	Behzadi et al. (2018)[4] Herbst et al. (2015)[3] Kanakamedala et al. (2018)[11] Berthold et al. (2021)[35] Lucidi et al. (2021)[22]

LFNS: lateral femoral notch sign, ACL: anterior cruciate ligament, MRI: magnetic resonance imaging, NA: not available.

Diagnosis and Prevalence

In the anterocentral part of the LFC, there is an anatomical groove named TS, known also as the lateral femoral notch, lateral femoral sulcus, lateral condylopatellar notch, or the sulcus terminalis (Fig. 3).[28,32,36] The TS divides the area of the anterior margin of the LFC contacting the tibia in full knee extension from the area of the femoral trochlea that articulates with the patella in deep knee flexion.[28,32,36-38] It is believed to develop due to an imprint of the anterior horn of the lateral meniscus (LM).[3,24,33,36,37] The mean depth of an anatomical TS ranges from 0.31 mm to 0.45 mm on plain radiographs and from 0.21 mm to 0.58 mm on magnetic resonance imaging (MRI) (Fig 3).[14,24,26,32,38] An LFC-IF is usually localized within the anatomical TS, increasing its anatomical depth, length, or width.[8-10,25-27,39] It can also be localized anterior or posterior to it, depending on the knee flexion angle during an ACL injury.[8,9,25,33,38]

The lateral femoral notch sign (LFNS), known also as deep sulcus sign or deep lateral femoral notch, is the radiological sign of the LFC-IF.[9-11,26,27] It is defined as the presence of an abnormally deep depression in the cortical line of the anterocentral part of the LFC.[9,10,26,27] Initially described by Warren et al.[27] in 1988 on plain radiographs, it has also been evaluated utilizing MRI.[4,9,10,26] Its depth is assessed on the sagittal MRI slice with the deepest impaction of the LFC, where a line tangent to the edges of the impaction is drawn. Then, the distance between the tangent line and the deepest part of the LFC-IF is measured (Fig. 3).[4,9,10,26,27]

Depending on the imaging modality and the cutoff value used, the prevalence of the LFNS in patients that sustained an ACL tear varies greatly. The presence of the LFNS with an ACL tear on plain radiographs or MRI according to the cutoff value used is summarized in Table 3. According to the cutoff value used, the sensitivity and specificity of the LFNS in ACL tears varied as well.

Table 4. LFC-IF in Acute and Chronic ACL Injuries

Study	No. of patients	Modality	Acute timeframe	Chronic timeframe	Difference
Warren et al. (1988)[27]	52 Patients with acute ACL tear, 101 patients with chronic ACL tear	X-ray	Not specified	Not specified	Utilizing LFC-IF cutoff > 1.5 mm, 2 of 52 patients (3.8%) in acute group had a positive LFC-IF compared to 13 of 101 (12.9%) in chronic group (p = 0.09).
Gentili et al. (1994)[14]	33 Patients with acute ACL tear, 13 patients with chronic ACL tear	MRI	Less than 1 month since injury	More than 3 months since injury	Mean depth of depression in acute group was 0.827 mm, compared with 0.419 mm in chronic group (NA, exact p-value not reported).
Yu et al. (1995)[32]	124 Patients with acute ACL tear and after 5 years of follow-up	X-ray	Index X-ray at mean time from injury 3 days	Next X-ray after 5 years of follow-up	In acute setting, mean depth of depression was 0.57 ± 0.57 mm (range 0–3.3 mm). At follow-up, the mean depth decreased significantly to 0.48 ± 0.56 mm (range, 0–2.3 mm; p < 0.05).
Garth et al. (2000)[33]	120 Patients with acute ACL tear, 44 patients with chronic ACL tear	X-ray	Less than 3 months since injury	More than 3 months since injury	Utilizing LFC-IF cutoff > 2 mm, 9 of 120 patients (7.5%) in acute group had a positive LFC-IF, compared to 2 of 44 (4.5%) in chronic group (p = 0.729).
Chang et al. (2014)[30]	89 Patients with acute ACL tear, 65 patients with chronic ACL tear	MRI	Mean of 18 days from injury, range 5–37 days	Mean of 733 days from injury (range, 201–1,915 days)	Utilizing LFC-IF cutoff > 1.5 mm, 37 of 89 patients (41.6%) in acute group had a positive LFC-IF, compared to 13 of 65 (20.0%) in chronic group While authors did not specify significance of this difference, performing chi-square with Yates correction test using provided data resulted in odds ratio of 2.85 (95% confidence interval, 1.36–5.96; p = 0.008).
Wierer et al. (2020)[10]	16 Patients with ACL reconstruction up to 3 months after injury and LFC-IF > 1.5 mm left untreated	MRI	Index MRI up to 3 months after injury	Next MRI after median follow-up of 9 years (range, 6–10 years)	Median area of LFC-IF decreased from 2.3 cm^2 (range, 0.9–3.8 cm^2) to 1.6 cm^2 (range, 0.4–3.2 cm^2) (p < 0.001). Median volume of LFC-IF decreased from 0.4 cm^3 (range, 0.1–0.8 cm^3) to 0.3 cm^3 (range, 0.1–0.6 cm^3) (p < 0.001). Median depth increased from 2.3 to 2.5 mm, but the range decreased from 2.0–3.6 to 1.3–3.6 mm (p > 0.05).

LFC-IF: lateral femoral condyle impaction fracture, ACL: Anterior Cruciate Ligament, MRI: magnetic resonance imaging, NA: not available.

The reported LFNS sensitivity with a cutoff of 0.9 mm was 51%,[21] with a cutoff > 1 mm, it ranged from 29.0% to 36.9%,[14,24,26] and with a cutoff > 1.5 mm, it ranged from 10% to 15.4%.[14,24,26,32] The LFNS specificity was reported to be high even for a cutoff of 0.9 mm (99%[21]) or cutoff > 1 mm (91% to 98.1%)[14,24,26] and to be 100% for all higher assessed cutoffs.[14,24,26,32]

LFC-IF in Acute and Chronic ACL Injuries

The evolution of LFC-IF over time is still a matter of de-

Table 5. Cartilaginous Injuries and Influence of LFC-IF on Osteoarthritis Development

Study	No. of patients	Modality	Time from injury	Cartilaginous injuries associated with LFC-IF and influence of LFC-IF on osteoarthritis development
Cobby et al. (1992)[24]	32 Patients with ACL tears and available MRI, 2 patients undergoing TKA	MRI, pathology	Not specified	Initial observation of association between LFC-IF and cartilage injury based on two cases undergoing total knee replacement and MRIs of 32 patients with ACL tear
Nakauchi et al. (2000)[25]	216 Patients after ACL tear, 66 with LFC-IF, no strict cutoff	Arthroscopy	During the removal of implants after ACLR	Authors reported that changes in the articular cartilage at the LFC-IF site were further advanced than at the time of ACLRs. They did not report such observations for patients with ACL tear without LFC-IF.
Garth et al. (2000)[33]	120 Patients with acute ACL tear, 44 patients with chronic ACL tear	Arthroscopy	Acute: less than 3 months from injury Chronic: more than 3 months from injury	Acute group: grade II chondral fissuring of the LFC was present in 9 of 9 knees (100%) with LFC-IF, compared with 9 of 111 knees (8%) without LFC-IF ($p = 0.001$). Chronic group: grade II chondral fissuring of LFC was present in arthroscopy in 2 of 2 knees (100%) with LFC-IF, compared with 4 of 42 knees (10%) without LFC-IF ($p = 0.001$).
Costa-Paz et al. (2001)[20]	21 Patients after ACL tear, 5 with LFC-IF, cutoff not defined	MRI	Index MRI shortly after ACL injury (not specified), next MRI at > 2 years of follow-up (range, 24–64 months; average, 34 months)	In 5 of 5 patients with LFC-IF, there was evidence of cartilage thinning from index MRI to follow-up and persistent subchondral bone depression.
Tauber et al. (2008)[39]	1 Patient with acute ACL tear	Arthroscopy	3 Days from injury	Fissuration of LFC was reported.
Frobell et al. (2011)[40]	61 Patients after ACL tear, 35 with LFC-IF > 1 mm	MRI	Index MRI up to 5 weeks after injury next MRI 2 years after injury	Change in cartilage thickness from index MRI to follow-up did not differ significantly between patients with present LFC-IF and those without LFC-IF. However, as pointed out in the accompanying commentary article by Potter,[41] the group of patients was heterogeneous; for example, some of them were treated conservatively and some by ACLR.[40]
Behzadi et al. (2018)[4]	52 Patients with MRI at 12 months of follow-up after ACL tear	MRI	12 Months after injury	The relaxation times, an early marker of cartilage degeneration, were elevated in ACL deficient patients with LFC-IF compared to ACL deficient patients without an LFC-IF (Δ7.4 ms; 95% CI, 5.6–9.2 ms; $p < 0.001$). Such differences between patients with and without LFC-IF were not significant for other regions of LFC cartilage. Within the group with an LFC-IF, the mean relaxation times were not associated with concomitant injuries other than an LFC-IF.
Wierer et al. (2020)[10]	16 Patients with ACLR up to 3 months after injury and LFC-IF > 1.5 mm left untreated	MRI	Index MRI up to 3 months after injury, next MRI after median follow-up of 9 years (range, 6–10 years)	Focal cartilage lesions within the area of the LFC-IF were found in 14 out of 16 patients. The median post-injury ICRS score was 1.5 ± 0.8 (range, 0–3), median increase was + 1.0, and median at follow-up was 2.0 ± 0.2 (range, 0–4, $p < 0.01$)

LFC-IF: lateral femoral condyle impaction fracture, ACL: anterior cruciate ligament, MRI: magnetic resonance imaging, TKA: total knee arthroplasty, CI: confidence interval, ACLR: anterior cruciate ligament reconstruction, ICRS: International Cartilage Repair Society.

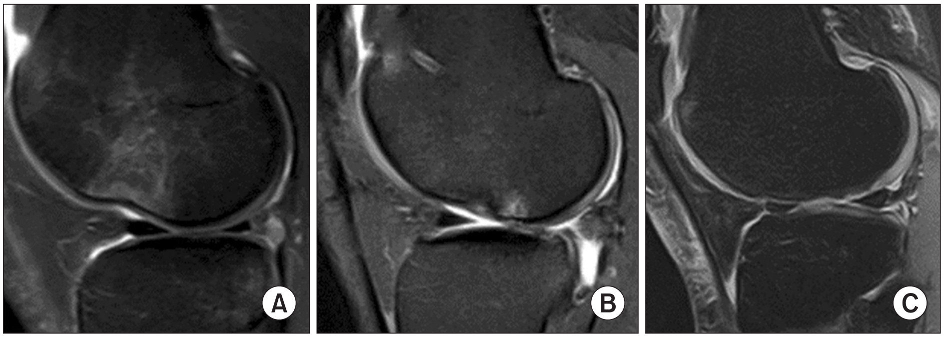

Fig. 4. Natural history of cartilage lesions after lateral femoral condyle impaction fracture (LFC-IF). (A) Acute LFC-IF. Anterior cruciate ligament reconstruction (ACLR) was performed, and the LFC-IF was left untreated. (B) At 3-year follow-up, notice full-thickness cartilage loss, subchondral edema, osteophyte formation, and degenerative tears of the posterior horn of lateral meniscus despite ACLR. (C) Another patient with subchondral osteophyte formation and cartilage degeneration in case of chronic untreated LFC-IF. Scans were done in slight knee flexion for (A) and (B), whereas scan was done in near knee extension for (C).

Table 6. Associations of LFC-IF with Decreased Knee Stability

Study	No. of patients	Method of stability assessment	Association of LFC-IF with decreased knee stability
Nakauchi et al. (2000)[25]	216 Patients after ACL tear, 66 with LFC-IF, no strict cutoff	Medical history taking	Authors reported episodes of "giving way" in 50% of patients with "abnormal notch," compared with 45% of patients with a normal TS (NS).
Chang et al. (2014)[30]	89 Patients with acute ACL tear, 65 patients with chronic ACL tear	Lachman and pivot-shift tests, quantified as high or low	Neither the Lachman test nor pivot-shift test was significantly correlated with the LFC-IF presence in both acute and chronic groups.
Sonnery-Cottet et al. (2017),[42] Anterolateral Ligament Expert Group Consensus	-	NA	The group proposed the presence of LFC-IF as a secondary criteria for anterolateral ligament reconstruction. However, it was not explained whether it was included due to the group's belief that LFC-IF on its own decreases stability or rather as a sign of more severe injury.
Kanakamedala et al. (2018)[11]	84 Patients with ACL tear, time from injury not specified. Some assessed with X-ray; some with MRI. LFC-IF with cutoff >2 mm: 3/66 in X-ray (4.5%) 6/64 in MRI (9.4%)	Lachman and pivot-shift tests, with an aid of accelerometers and skin markers	Both for the pivot-shift and Lachman tests, there were no significant correlations between LFC-IF depth and ipsilateral lateral compartment translation or acceleration. However, the mean depth of the analyzed notches was only 0.8 ± 0.7 mm on X-ray and 1.0 ± 0.7 mm on MRI scans. Only 3 of 66 notches on X-ray (4.5%) and 6 of 64 notches on MRI (9.4%) exceeded the cutoff of 2 mm in depth. Furthermore, the authors stated that the study was limited by a small sample size, resulting in calculated power of 0.67.
Dimitriou et al. (2020)[21]	100 Patients with ACL tear, 17 with LFC-IF > 1.8 mm	Lachman, anterior drawer and pivot-shift tests	Patients with LFC-IF > 1.8 mm were at a higher risk of residual pivot-shift (35% [6/17]) than those with lateral femoral notch < 1.8 mm (8% [7/83]). The same was true for ACL graft rupture (12% [2/17] vs. 2.4% [2/83], respectively). RR for either residual pivot-shift or ACL graft rupture was calculated to be 4.2 (95% CI, 1.6–11.1; $p < 0.01$).
Lucidi et al. (2021)[22]	90 Patients after ACL tear, 47 with LFC-IF > 1 mm, 10 with LFC-IF > 2 mm	Pivot shift performed with the aid of navigation system during the preoperative examination under anesthesia	Authors reported LFC-IF deeper than 2 mm was significantly correlated with an increased pivot-shift (pivot-shift acceleration, $p = 0.0385$; pivot shift internal-external rotation, $p = 0.0423$). No significant difference in stability was present between patients with a normal notch depth and those with an LFC-IF between 1 and 2 mm.

LFC-IF: lateral femoral condyle impaction fracture, ACL: anterior cruciate ligament, TS: terminal sulcus, NA: not available, MRI: magnetic resonance imaging, RR: relative risk, CI: confidence interval.

bate. Some authors suggested that due to the decrease of the depth, area, or volume of an LFC-IF, the diagnostic value of an LFNS differs in acute and chronic ACL injuries.[28,32,33)] It is uncertain whether such decrease would result from subchondral bone healing or from osteophyte formation.[8,32)] Among the included studies, 6 studies compared LFC-IF in acute vs. chronic ACL injuries.[10,14,27,30,32,33)] In 3 studies, there were no differences reported between acute and chronic groups in terms of the prevalence, depth, area, or volume of an LFC-IF,[14,27,33)] while in the other 3 studies, depth, prevalence, area, or volume was higher in acute than chronic cases[10,30,32)] as summarized in Table 4.

Cartilaginous Injuries Associated with LFC-IF and Influence of LFC-IF on Osteoarthritis Development

A compression fracture of the LFC is inevitably associated with cartilage damage. Among 8 studies reporting on cartilaginous injuries associated with LFC-IF or the influence of LFC-IF on osteoarthritis development,[4,10,20,24,25,33,39,40)] 7 confirmed the impact of LFC-IF on cartilage injury and osteoarthritis development[4,10,20,24,25,33,39)] as summarized in Table 5. In Fig. 4, the natural history of cartilage lesions after LFC-IF on MRI in the authors' own data is presented.

Associations of LFC-IF with Decreased Knee Stability

LFC-IF has been compared to Hill-Sachs lesions occurring during anterior shoulder dislocations[3,9,11,14-17)] and it has been proposed to be correlated with decreased knee stabil-

Table 7. Lateral Meniscus Injuries Concomitant with LFC-IF

Study	No. of patients (percentage of LFC-IF)	Lateral meniscus injuries concomitant with LFC-IF
Garth et al. (2000)[33)]	120 Patients with acute ACL tear, 44 patients with chronic ACL tear, LFC-IF with cutoff > 2 mm: 9 LFC-IF and 5 lateral condyle depressions below cutoff /120 acute ACL tears; 2 LFNS and 1 lateral condyle depression below cutoff /44 chronic ACL tears	LM injury in 10/11 (90.9%) acute or chronic LFC-IF and 4/6 (6.7%) with acute or chronic lateral condyle depression below cutoff, compared to 44/147 (29.9%) knees without these features ($p = 0.001$) AHLM injury in 5/17 (29.4%) knees with acute or chronic LFC-IF or lateral condyle depression below cutoff, compared with 1/147 (0.7%) knees without these features ($p = 0.001$)
Nakauchi et al. (2000)[25)]	216 Patients after ACL tear, 66 with LFC-IF, no strict cutoff	LM injury in 46/66 (69.7%) knees with LFC-IF, compared with 63/150 (42.0%) knees without LFC-IF ($p < 0.005$)
Kijowski et al. (2012)[1)]	114 Patients after ACL tear, 40 with LFC-IF, cutoff not defined	LM injury in 24/40 (60.0%) patients with LFC-IF, compared with 27/73 (37.0%) patients without LFC-IF ($p = 0.03$)
Herbst et al. (2015)[3)]	500 Patients after ACL tear, LFC-IF with cutoff > 2 mm: 132/500 in X-ray (26.4%); 109/500 in MRI (21.8%)	LM injury in 53/132 (40.2%) patients with LFC-IF, compared with 96/368 (26.1%) patients without LFC-IF ($p = 0.004$) Among 53 patients with LFC-IF and LM injury, 23 had PHLM injury, 14 had bucket-handle injury, 13 had AHLM injury, and 3 had both AHLM and PHLM injury
Kanakamedala et al. (2018)[11)]	84 Patients with ACL tear, some assessed with X-ray and some with MRI. LFC-IF with cutoff > 2 mm: 3/66 in X-ray (4.5%) 6/64 in MRI (9.4%)	Mean LFC-IF depth was significantly greater for patients with LM injury than for patients without LM injury (X-ray: 0.6 vs. 1.0 mm, $p < 0.05$; MRI: 0.8 vs. 1.2 mm, $p < 0.05$).
Lodewijks et al. (2019)[26)]	65 Patients with ACL tear, LFC-IF with cutoff > 1 mm: 24/65 (36.9%), including 10/65 with cutoff ≥ 1.5 mm (15.4%)	Median LFC-IF depth in ACL-injured group with LM injury was 1.1 mm vs. 0.6 mm in patients without LM injury ($p = 0.012$). 80% of the 10 ACL-injured patients with LFC-IF depth ≥ 1.5 mm had LM injury compared to only 33% of patients (18 of 55 patients) with an LFC-IF depth < 1.5 mm, resulting in OR of 8.2 (95% CI, 1.6–42.7; $p = 0.011$).
Bernholt et al. (2020)[9)]	825 Patients with ACL tear, LFC-IF with cutoff > 1.5 mm or a second notch: 214/825 (25.9%)	LM injury in 66.7% of knees with LFC-IF compared with 53.9% of knees without LFC-IF (OR, 1.7; 95% CI, 1.2–2.4; $p = 0.001$). PRLM injuries were present in 17.1% of knees with LFNS compared with 11.1% of knees without ($p = 0.03$).
Berthold et al. (2021)[35)]	115 Patients with ACL tear, LFC-IF with cutoff > 2 mm: 22/115 (19.6%)	Patients with PRLM injury were 5.3 times more likely to have LFC-IF in comparison to patients without PRLM injury (95% CI, 1.97–14.09; $p < 0.001$)

LFC-IF: lateral femoral condyle impaction fracture, ACL: anterior cruciate ligament, LFNS: lateral femoral notch sign, LM: lateral meniscus, AHLM: anterior horn of lateral meniscus, MRI: magnetic resonance imaging, PHLM: posterior horn of lateral meniscus, OR: odds ratio, CI: confidence interval, PRLM: posterior root of lateral meniscus.

ity.[21,22] Five original studies and one consensus paper concerned this issue. While 3 original studies did not confirm association of LFC-IF with decreased knee stability,[11,25,30] 2 more recent studies confirmed that LFC-IF may be associated with decreased rotational stability,[21,22] especially in deep cases (> 1.8 mm[21] or > 2 mm[22]) as summarized in Table 6.

Lesions Concomitant to LFC-IF

Apart from bone bruises and chondral lesions, the most frequent concomitant lesion was an injury of the LM with the prevalence ranging from 40.2% to 90.9%.[1,3,9,11,25,26,35] It is uncertain which part of the LM is at the greatest risk of injury in case of an LFC-IF. Different authors suggested anterior horn,[33] posterior horn,[3] or posterior root.[9,35] Literature concerning LM injuries concomitant to LFC-IF is summarized in Table 7 and a few cases of LM injury concomitant to LFC-IF are presented in Fig. 5.

In assessing concomitant injuries with LFC-IF, most studies did not document an increased risk of a medial meniscus (MM) tear,[1,3,5,11,25,33] medial collateral ligament injury,[9,25] lateral collateral ligament injury,[9] and posterior cruciate ligament injury.[9] Interestingly, Bernholt et al.[9] reported that MM ramp lesions were present in 27.1% of knees with an LFNS compared with 15.6% of knees without it (odds ratio, 2.0; 95% confidence interval, 1.4–2.9; $p = 0.001$).[9] One study each reported an increased risk of a Segond fracture[16] and posterolateral corner injury.[9] As to an anterolateral ligament injury, 1 study reported an increased risk,[21] while another one denied it.[34] The prevalence of LFC-IF was decreased in

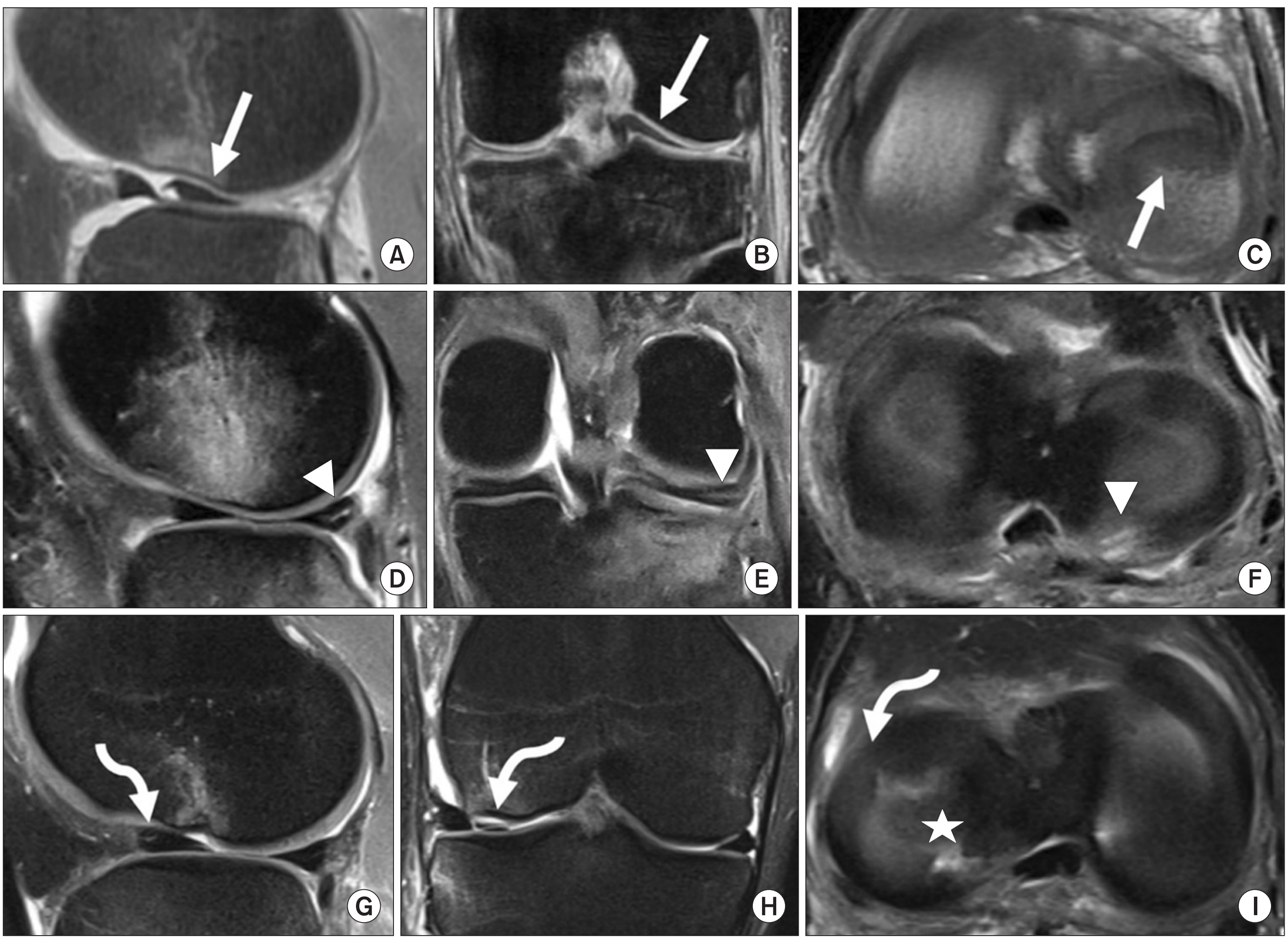

Fig. 5. Lateral meniscus injuries concomitant with lateral femoral condyle impaction fracture. (A-C) Patient with bucket handle injury of posterior horn of lateral meniscus (PHLM). Displaced PHLM can be seen on sagittal slice (arrow; A), as well as on coronal slice (arrow; B) and axial slice (arrow; C). (D-F) Patient with horizontal complex injury of PHLM. PHLM injury can be seen on sagittal slice (arrowhead; D), as well as on coronal slice (arrowhead; E) and axial slice (arrowhead; F). (G-I) Patient with injury of both anterior horn of lateral meniscus (AHLM) and PHLM. AHLM injury can be seen on sagittal slice (curved arrow; G), as well as on coronal slice (curved arrow; H) and axial slice (curved arrow; I). On axial slice, PHLM injury near the lateral meniscus posterior root can be seen (asterisk; I).

combined injury of ACL and posterolateral corner (7.2% vs. 0.9%, $p = 0.001$).[9]

Management

Four treatment methods of LFCIF were presented in the literature: 3 case reports and 1 technique description. Garth and Wilson[43] performed an open reduction and internal fixation with a Herbert screw through an anterolateral arthrotomy. To elevate the LFC depression, a cortical window was created and filled with autograft harvested from the proximal tibia. The ACL reconstruction and partial medial meniscectomy were postponed by 60 days after the initial procedure. Sadlo and Nebelung[12] performed an ACL reconstruction with a concomitant reduction of an LFC-IF. The fracture was reduced with a dilatator and chisel and fixated with an interference screw, without use of any bone graft. In the case report by Tauber et al.,[39] the fracture was reached by a 3.2-mm tunnel drilled from an additional small incision on the lateral side of the LFC. The fracture was reduced with an elevator introduced through the tunnel and filled with cancellous allograft. The ACL reconstruction and partial lateral meniscectomy were performed simultaneously. The most recent technique was proposed by Malinowski et al.,[17] who reduced the LFC-IF through an enlarged anterolateral portal. The osteochondral flap covering the LFC-IF was mobilized using an osteotome and the gap was filled with the crushed cancellous bone allograft. Then, the flap was sutured to the periosteum to restore the shape of the LFC. In all cases, good clinical and radiological outcomes were achieved at follow-up of 6 months,[12,17] 5 years,[43] and 10 years.[39]

DISCUSSION

According to the authors' knowledge, this is the first literature review covering the topic of LFC-IF. Furthermore, this review was performed in two major databases, within the bibliographies of included studies and using "Cited In" option independently by two authors in the stepwise manner—according to the PRISMA extension for the scoping reviews. While in some issues a definite answer could not be drawn from the available literature, this represents a limitation in the available literature rather than in the review process. Therefore, this study provides an up-to-date summary on the topic of LFC-IF diagnosis, prevalence, clinical importance, and management. As to clinical relevance of this review, LFC-IF can be present in up to 52% of cases of ACL tears and it increases risk of cartilage deterioration, risk of concomitant injuries, and possibly risk of greater knee rotational instability, underlining possible importance of LFC-IF in regards to ACL reconstruction functional outcomes and the need for revision. With so many ways in which LFC-IF may influence the final outcomes of ACL tear treatment, providing clinicians with an overview of the rising body of the literature seems to be of high clinical relevance.

This study is not free of possible limitations inherent to any literature review, such as missing relevant articles or biased inclusion of given studies. However, as mentioned above, the process of literature search was thorough and selection and extraction was performed independently by two authors. Another limitation is that while LFC-IF are often accompanied by similar impaction fractures on the LTP, this study only concerned LFC-IF. Literature concerning LTP impaction fractures (LTP-IF) was not reviewed in this study for two reasons: first, in order to keep this review succinct; and second, because LTP-IF are already better described than LFC-IF and there are even several classifications of LTP-IF created.[9,44] The authors believed that including the amount of available data concerning LTP-IF would decrease the transparency of this review and make it harder to analyze the data. The issue of LTP-IF surely needs further investigation.

An LFC-IF occurs in the area of the TS due to the pivot-shift mechanism of ACL injury. Its radiological feature, the LFNS, is defined as an impaction of TS deeper than 1 mm and is present in up to 52% of patients with a torn ACL. It is still unclear if the LFC-IF depth or volume tends to decrease after the initial trauma or not; however, it causes injury to the cartilage and probably leads to its progressive degeneration. An LFC-IF is significantly associated with an increased risk of an LM injury. A large LFC-IF might be associated with greater rotational knee instability. Although several techniques of LFC-IF treatment were proposed, none of them has been evaluated in a large cohort of patients to date.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Kijowski R, Sanogo ML, Lee KS, et al. Short-term clinical importance of osseous injuries diagnosed at MR imaging in patients with anterior cruciate ligament tear. Radiology. 2012;264(2):531-41.
2. Sonnery-Cottet B, Thaunat M, Freychet B, Pupim BH, Murphy CG, Claes S. Outcome of a combined anterior cruciate ligament and anterolateral ligament reconstruction technique with a minimum 2-year follow-up. Am J Sports Med. 2015; 43(7):1598-605.
3. Herbst E, Hoser C, Tecklenburg K, et al. The lateral femoral notch sign following ACL injury: frequency, morphology and relation to meniscal injury and sports activity. Knee Surg Sports Traumatol Arthrosc. 2015;23(8):2250-8.
4. Behzadi C, Welsch GH, Petersen JP, et al. T2 relaxation times of the anterolateral femoral cartilage in patients after ACL-reconstruction with and without a deep lateral femoral notch sign. Eur J Radiol. 2018;106:85-91.
5. Frobell RB, Roos HP, Roos EM, et al. The acutely ACL injured knee assessed by MRI: are large volume traumatic bone marrow lesions a sign of severe compression injury? Osteoarthritis Cartilage. 2008;16(7):829-36.
6. Fayad LM, Parellada JA, Parker L, Schweitzer ME. MR imaging of anterior cruciate ligament tears: is there a gender gap? Skeletal Radiol. 2003;32(11):639-46.
7. Yoon KH, Yoo JH, Kim KI. Bone contusion and associated meniscal and medial collateral ligament injury in patients with anterior cruciate ligament rupture. J Bone Joint Surg Am. 2011;93(16):1510-8.
8. Hoffelner T, Pichler I, Moroder P, et al. Segmentation of the lateral femoral notch sign with MRI using a new measurement technique. BMC Musculoskelet Disord. 2015;16:217.
9. Bernholt DL, DePhillipo NN, Crawford MD, Aman ZS, Grantham WJ, LaPrade RF. Incidence of displaced posterolateral tibial plateau and lateral femoral condyle impaction fractures in the setting of primary anterior cruciate ligament tear. Am J Sports Med. 2020;48(3):545-53.
10. Wierer G, Simetinger T, Hudelmaier M, Moroder P, Hoffelner T. Fate of the lateral femoral notch following early anterior cruciate ligament reconstruction. Knee. 2020;27(2):414-9.
11. Kanakamedala AC, Burnham JM, Pfeiffer TR, et al. Lateral femoral notch depth is not associated with increased rotatory instability in ACL-injured knees: a quantitative pivot shift analysis. Knee Surg Sports Traumatol Arthrosc. 2018;26(5): 1399-405.
12. Sadlo PA, Nebelung W. Arthroscopically assisted reduction of a lateral femoral notch in acute tear of the anterior cruciate ligament. Arthroscopy. 2006;22(5):574.
13. Palmieri-Smith RM, Wojtys EM, Potter HG. Early cartilage changes after anterior cruciate ligament injury: evaluation with imaging and serum biomarkers: a pilot study. Arthroscopy. 2016;32(7):1309-18.
14. Gentili A, Seeger LL, Yao L, Do HM. Anterior cruciate ligament tear: indirect signs at MR imaging. Radiology. 1994; 193(3):835-40.
15. Losee RE, Johnson TR, Southwick WO. Anterior subluxation of the lateral tibial plateau: a diagnostic test and operative repair. J Bone Joint Surg Am. 1978;60(8):1015-30.
16. Stallenberg B, Gevenois PA, Sintzoff SA Jr, Matos C, Andrianne Y, Struyven J. Fracture of the posterior aspect of the lateral tibial plateau: radiographic sign of anterior cruciate ligament tear. Radiology. 1993;187(3):821-5.
17. Malinowski K, Mostowy M, Goralczyk A, LaPrade RF, Hermanowicz K. Technique for treatment of subchondral compression fracture of the lateral femoral condyle associated with ACL tear. Arthrosc Tech. 2020;9(6):e823-8.
18. Zhang L, Hacke JD, Garrett WE, Liu H, Yu B. Bone bruises associated with anterior cruciate ligament injury as indicators of injury mechanism: a systematic review. Sports Med. 2019;49(3):453-62.
19. Patel SA, Hageman J, Quatman CE, Wordeman SC, Hewett TE. Prevalence and location of bone bruises associated with anterior cruciate ligament injury and implications for mechanism of injury: a systematic review. Sports Med. 2014; 44(2):281-93.
20. Costa-Paz M, Muscolo DL, Ayerza M, Makino A, Aponte-Tinao L. Magnetic resonance imaging follow-up study of bone bruises associated with anterior cruciate ligament ruptures. Arthroscopy. 2001;17(5):445-9.
21. Dimitriou D, Reimond M, Foesel A, et al. The deep lateral femoral notch sign: a reliable diagnostic tool in identifying a concomitant anterior cruciate and anterolateral ligament injury. Knee Surg Sports Traumatol Arthrosc. 2021;29(6): 1968-76.
22. Lucidi GA, Grassi A, Di Paolo S, et al. The lateral femoral notch sign is correlated with increased rotatory laxity after anterior cruciate ligament injury: pivot shift quantification with a surgical navigation system. Am J Sports Med. 2021;49(3):649-55.
23. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018;169(7):467-73.
24. Cobby MJ, Schweitzer ME, Resnick D. The deep lateral femoral notch: an indirect sign of a torn anterior cruciate ligament. Radiology. 1992;184(3):855-8.

25. Nakauchi M, Kurosawa H, Kawakami A. Abnormal lateral notch in knees with anterior cruciate ligament injury. J Orthop Sci. 2000;5(2):92-5.

26. Lodewijks PC, Delawi D, Bollen TL, Dijkhuis GR, Wolterbeek N, Zijl JA. The lateral femoral notch sign: a reliable diagnostic measurement in acute anterior cruciate ligament injury. Knee Surg Sports Traumatol Arthrosc. 2019;27(2):659-64.

27. Warren R, Kaplan N, Bach B. The lateral notch sign of anterior cruciate ligament insufficiency. Am J Knee Surg. 1988;1:119-24.

28. Jones AR, Finlay DB, Learmonth DJ. A deep lateral femoral notch as a sign of acutely torn anterior cruciate ligament. Injury. 1993;24(9):601-2.

29. Yeung KW, Liu GC, Wu DK. Tear of the anterior cruciate ligament: evaluation with MR imaging. Kaohsiung J Med Sci. 1998;14(2):88-93.

30. Chang MJ, Chang CB, Choi JY, Je MS, Kim TK. Can magnetic resonance imaging findings predict the degree of knee joint laxity in patients undergoing anterior cruciate ligament reconstruction? BMC Musculoskelet Disord. 2014;15:214.

31. Celikyay F, Yuksekkaya R, Bilgic E. A retrospective comparison of ACL tear and mucoid degeneration MRI findings and an emphasis on evaluating of ACL, blumensaat, and PCL angles. J Belg Soc Radiol. 2020;104(1):36.

32. Yu JS, Bosch E, Pathria MN, et al. Deep lateral femoral sulcus: study of 124 patients with anterior cruciate ligament tear. Emerg Radiol. 1995;2(3):129-34.

33. Garth WP Jr, Greco J, House MA. The lateral notch sign associated with acute anterior cruciate ligament disruption. Am J Sports Med. 2000;28(1):68-73.

34. Marot V, Corin B, Reina N, Murgier J, Berard E, Cavaignac E. Femoral and tibial bone bruise volume is not correlated with ALL injury or rotational instability in patients with ACL-deficient knee. Knee Surg Sports Traumatol Arthrosc. 2021;29(3):900-6.

35. Berthold DP, Muench LN, Herbst E, et al. High prevalence of a deep lateral femoral notch sign in patients with anterior cruciate ligament (ACL) and concomitant posterior root tears of the lateral meniscus. Knee Surg Sports Traumatol Arthrosc. 2021;29(4):1018-24.

36. Danzig LA, Newell JD, Guerra J Jr, Resnick D. Osseous landmarks of the normal knee. Clin Orthop Relat Res. 1981;(156):201-6.

37. Harrison RB, Wood MB, Keats TE. The grooves of the distal articular surface of the femur: a normal variant. AJR Am J Roentgenol. 1976;126(4):751-4.

38. Grimberg A, Shirazian H, Torshizy H, Smitaman E, Chang EY, Resnick DL. Deep lateral notch sign and double notch sign in complete tears of the anterior cruciate ligament: MR imaging evaluation. Skeletal Radiol. 2015;44(3):385-91.

39. Tauber M, Fox M, Koller H, Klampfer H, Resch H. Arthroscopic treatment of a large lateral femoral notch in acute anterior cruciate ligament tear. Arch Orthop Trauma Surg. 2008;128(11):1313-6.

40. Frobell RB. Change in cartilage thickness, posttraumatic bone marrow lesions, and joint fluid volumes after acute ACL disruption: a two-year prospective MRI study of sixty-one subjects. J Bone Joint Surg Am. 2011;93(12):1096-103.

41. Potter HG. Commentary on an article by Richard B. Frobell, PhD: "Change in cartilage thickness, posttraumatic bone marrow lesions, and joint fluid volumes after acute ACL disruption. a two-year prospective MRI study of sixty-one subjects". J Bone Joint Surg Am. 2011;93(12):e71.

42. Sonnery-Cottet B, Daggett M, Fayard JM, et al. Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament: deficient knee. J Orthop Traumatol. 2017;18(2):91-106.

43. Garth WP Jr, Wilson T. Open reduction of a lateral femoral notch associated with an acute anterior cruciate ligament tear. Arthroscopy. 2001;17(8):874-7.

44. Ciszkowska-Lyson B, Dominik B, Zdanowicz U, Smigielski R. Proposing an MRI-based classification system allowing proper assessment of the damage to the posteriori edge of the tibia. Poster session presented at: 2018 European Congress of Radiology; 2018 Feb 28-2018 Mar 4. C-3210.