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Treatment of avulsion fractures around the knee

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Avulsion fractures of the knee occur when tensile forces cause a bone fragment to separate at the site of soft tissue attachment. These injuries, which frequently affect adolescent athletes, can involve the cruciate and collateral ligaments, arcuate complex, iliotibial band, and patellar and quadriceps tendons. Radiographs aid in the initial diagnosis, while computed tomography and magnetic resonance imaging facilitate a comprehensive evaluation of injury severity and concomitant damage. Specific avulsion fracture types include: anterior cruciate ligament avulsions (tibial site, Meyers and McKeever classification), posterior cruciate ligament avulsions (tibial attachment, Griffith's classification), Segond fractures (anterolateral complex injury), iliotibial band avulsions, medial collateral ligament avulsions (reverse Segond, Stieda fractures), arcuate complex avulsions (arcuate sign), medial patellofemoral avulsions (patellar dislocations), and patellar/quadriceps tendon avulsions. The treatment depends on the fracture location, displacement, and associated injuries. Nondisplaced fractures can be managed conservatively, while displaced fractures or those with instability require surgical reduction and fixation. Prompt recognition and appropriate intervention prevent complications such as deformity, nonunion, malunion, and residual instability. This review provides an overview of the pathogenesis, diagnosis, and management of knee avulsion fractures to guide clinical decision-making.

Keywords: Knee; Avulsion fracture; Collateral ligaments; Anterior cruciate ligament; Posterior cruciate ligament

Review Article

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Introduction

An avulsion fracture occurs when tensile forces result in the separation of a bone fragment from its primary osseous structure. This pathology may manifest at any osteotendinous junction where soft tissue maintains its attachment to the bone [1]. This condition occurs with particular frequency among participants in organized athletic activities, notably in the adolescent athletic population [2].

An avulsion fracture results from an acute traumatic event where sudden forceful traction causes osseous tissue separation. At the knee joint, these avulsion injuries may affect multiple anatomic components, including the cruciate and collateral ligaments, arcuate ligament complex, iliotibial band (ITB), patellar and quadriceps tendons, and retinacular structures [3].

Primary diagnostic assessment commonly employs radiographic imaging to detect subtle indicators of avulsion fractures, specifically the presence of small osseous fragments at physiologic attachment sites [4]. Supplementary imaging modalities, specifically computed tomography (CT) and magnetic resonance imaging (MRI), yield comprehensive diagnostic information regarding injury severity and extent [5]. This manuscript presents a comprehensive review of avulsion fracture patterns and therapeutic approaches specific to the knee region.

Anterior Cruciate Ligament Avulsion Fracture

The anterior cruciate ligament (ACL) comprises dense connective tissue that originates from the posterior aspect of the lateral femoral condyle and courses anteriorly, medially, and distally to its tibial insertion. The ligament's fibers expand to insert into a broad, concave fossa situated anterior and lateral to the medial tibial spine. The ACL serves as a critical stabilizing structure within the knee joint, providing resistance against anterior tibial translation and rotational forces [6]. The ACL provides resistance to anterior tibial translation during deep knee flexion in conjunction with adjacent soft tissue structures, while independently restraining this motion near terminal extension [7,8]. Pediatric patients demonstrate a higher incidence of ACL avulsion fractures compared to adults, attributed to the relative structural vulnerability of the apophysis compared to ligamentous tissue [5]. Avulsion fractures of the ACL predominantly occur at the tibial insertion site, with less frequent involvement of the lateral femoral condyle [9]. The primary injury mechanisms include pivot shift trauma, comprising valgus force and internal rotation of the flexed knee, as well as hyperextension injury [4]. Early detection is essential for optimal clinical outcomes, as unrecognized ACL avulsion injuries may progress, rendering conservative interventions ineffective and potentially leading to complications [10]. Chronic cases, frequently resulting from missed diagnosis or suboptimal nonoperative management, typically present with extension limitation and pain due to impingement from nonunion or malunion fragments within the intercondylar notch [11,12]. Although conventional radiographs may demonstrate limited sensitivity in fracture detection, advanced imaging modalities including CT and MRI provide detailed anatomic evaluation, enabling assessment of ACL integrity and associated structures. MRI demonstrates particular utility in identifying concomitant injuries, such as meniscal tears, which require appropriate therapeutic interventions [4,13]. The Meyers and McKeever classification system categorizes tibial spine fractures into four distinct subtypes [14]. Type I fractures, characterized by nondisplacement, are amenable to conservative management (Fig. 1). The optimal treatment strategy for type II fractures, which is partially displaced, remains controversial. However, displaced fractures, classified as types III and IV, necessitate reduction and fixation through either arthroscopic or open surgical approaches [15,16].

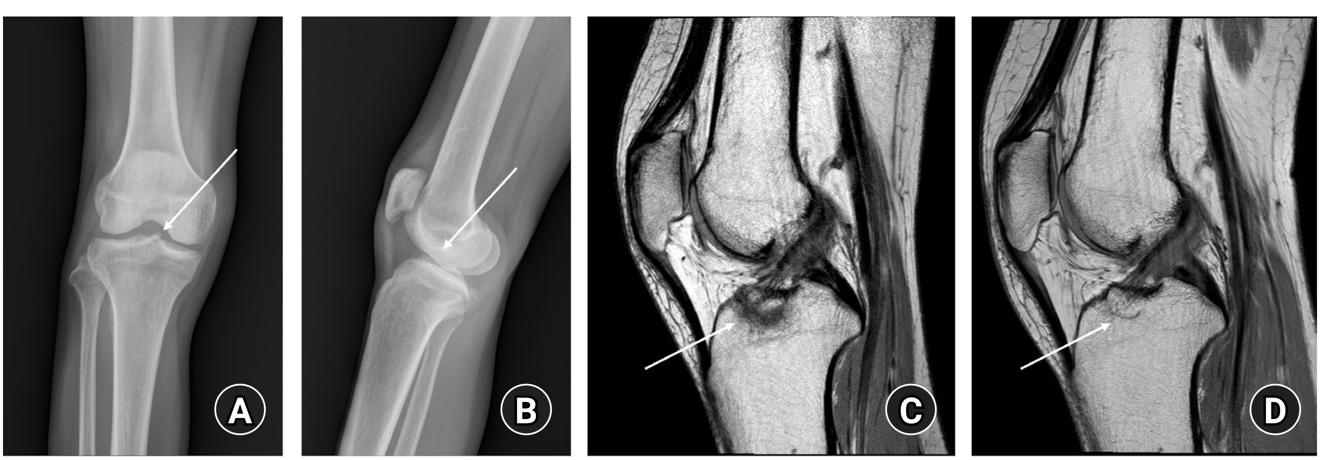

Fig. 1. A 37-year-old female patient sustained an injury from a fall from the third floor. On plain anteroposterior (A) and lateral (B) radiographs, a nondisplaced anterior cruciate ligament (ACL) avulsion fracture (arrow) is observed. (C) On sagittal proton density-weighted magnetic resonance imaging (MRI), a non-displaced ACL avulsion fracture (arrow) is observed, and the ACL continuity remains intact. (D) Conservative treatment was administered, and a follow-up MRI after 6 months confirmed bone union (arrow).

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Posterior Cruciate Ligament Avulsion Fracture

The posterior cruciate ligament (PCL) functions as the principal stabilizer against posterior tibial translation, particularly during 90° knee flexion. In vitro investigations demonstrate increased medial compartment contact pressures in PCL-deficient knees [17]. Although PCL injuries occur less frequently than ACL injuries, delayed diagnosis may lead to chronic instability and premature degenerative changes, resulting in significant functional impairment [6]. PCL avulsion fractures share similar injury mechanisms with intrasubstance PCL tears, frequently occurring during motor vehicle or motorcycle accidents [18]. These injuries typically result from posteriorly directed forces applied to the proximal tibia in knee flexion, with tibial-sided PCL avulsion being the predominant pattern [19]. Initial diagnostic evaluation employs plain radiographs, with lateral view providing optimal visualization. Stress radiographs enhance diagnostic accuracy by demonstrating posterior tibial translation [20]. When radiographs prove inconclusive, CT or MRI provide supplementary diagnostic information. Given the high prevalence of concomitant injuries, MRI evaluation is strongly recommended [18,21]. MRI demonstrates excellent diagnostic precision for PCL avulsion injuries, visualized as discrete osseous fragments attached to intact PCL tissue, with reported accuracy rates of 96%–100% [22,23]. Displaced PCL avulsion fractures require surgical reduction and fixation to maintain joint stability and prevent nonunion, while nondisplaced fractures demonstrate favorable outcomes with conservative management (Fig. 2). Current literature supports nonoperative treatment for fractures with displacement up to 5 mm, as reported by Zhao et al. [24]. More recently, Yoon et al. [25] suggested considering conservative management for acute PCL avulsion fractures with displacement up to 6.7 mm. Griffith's classification system delineates three fracture types with corresponding treatment algorithms. Type I (nondisplaced) fractures respond to conservative management with casting in 15° knee flexion. Type II fractures (mild displacement with posterior elevation) may be managed either conservatively or surgically. Type III fractures (complete displacement) typically necessitate surgical fixation through arthroscopic or open approaches [26]. Surgical techniques encompass various fixation methods utilizing screws, K-wires, anchors, or sutures, performed via either open or arthroscopic approaches [18,19].

Segond Fracture

Segond [27] initially described the eponymous fracture through cadaveric studies as an avulsion fracture occurring at the proximolateral tibial aspect. Subsequent investigations by Kaplan [28] established its relationship with

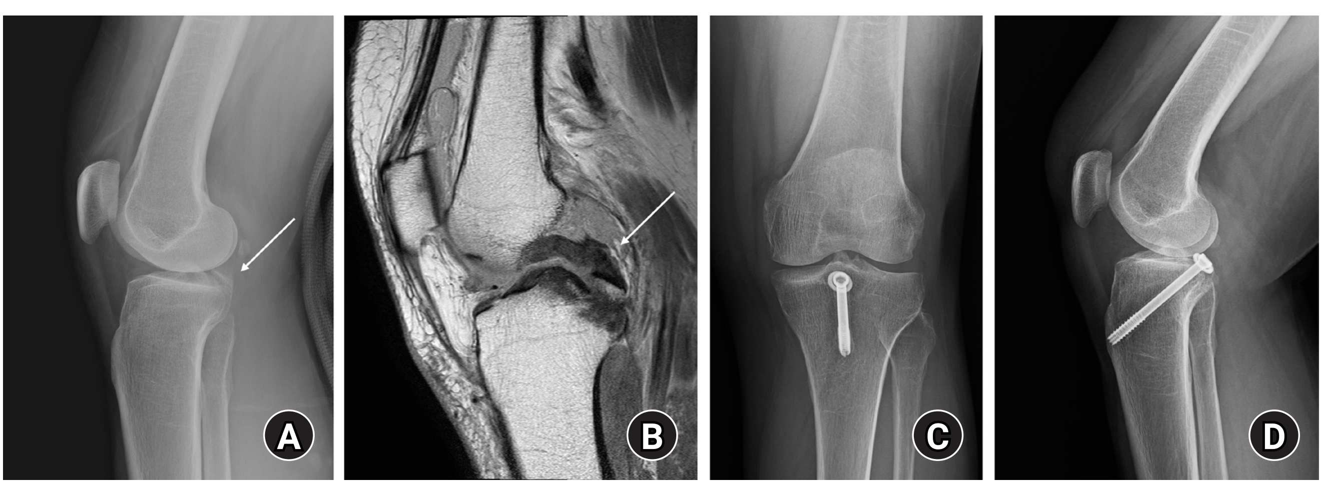

Fig. 2. A 57-year-old female patient was admitted following a motorcycle accident. (A) A posterior cruciate ligament (PCL) avulsion (arrow) is noted on a knee lateral radiograph. (B) On sagittal proton density-weighted magnetic resonance imaging, a displaced PCL avulsion fracture (arrow) is observed, but the continuity is intact. (C, D) Bone union was achieved 1 year after surgical treatment.

ITB avulsion, while Terry et al. [29] further elucidated the involvement of deep capsulo-osseous ITB fibers in the fracture pathology. The identification of the anterolateral ligament (ALL) in 2013 suggested its potential role in Segond fracture pathogenesis [30]. The International ALC Consensus Group's 2017 statement acknowledged multiple anatomic structures, including the ALL, deep ITB, and biceps aponeurosis, attach at the Segond fracture site, with definitive pathologic attribution remaining uncertain [31]. Although the precise mechanism remains incompletely defined, tibial internal rotation appears contributory to fracture development. The association between Segond fractures and ACL injuries is well-established [32-34], with concurrent meniscal pathology frequently reported [35-37]. Segond fractures occur in 7.4% of patients undergoing ACL reconstruction, with an increased prevalence of 15.2% when including healed fractures [38]. While radiographic diagnosis of Segond fractures is straightforward, MRI evaluation remains essential given the frequency of concomitant injuries (Fig. 3).

Therapeutic intervention primarily addresses associated injuries rather than the Segond fracture specifically. The fracture serves as a pathognomonic indicator for ACL injury, necessitating ligament reconstruction. However current evidence does not support surgical fixation of Segond fractures. These injuries demonstrate spontaneous healing in approximately 36% of cases and do not increase ACL reconstruction revision risk. However, subtle residual laxity may predispose patients to secondary meniscal injury or accelerated osteoarthritis [38]. Indications for lateral augmentation procedures, including ALL reconstruction or lateral extraarticular tenodesis, encompass Segond fracture, chronic ACL pathology, grade III pivot shift, high-level athletic participation, pivoting sports involvement, or ACL revision surgery [31,39-42]. Recent systematic analyses suggest Segond fractures do not adversely affect ACL reconstruction outcomes, demonstrating no significant correlation with high-grade Lachman or pivot-shift findings [43]. Additional investigation regarding optimal Segond fracture management remains warranted.

Iliotibial Band Avulsion Fracture

The ITB integrates the tensor fascia lata tendon with fascia lata fibers, functioning as a key anterolateral knee stabilizer. Its anatomical structure comprises a superficial component attaching to Gerdy's tubercle and a deep component inserting into the distal femoral intermuscular septum, facilitating both stability and functional integration with adjacent tissues [44]. ITB avulsion fractures occur through an atypical mechanism involving isolated varus force application to the knee, contrasting with conventional knee

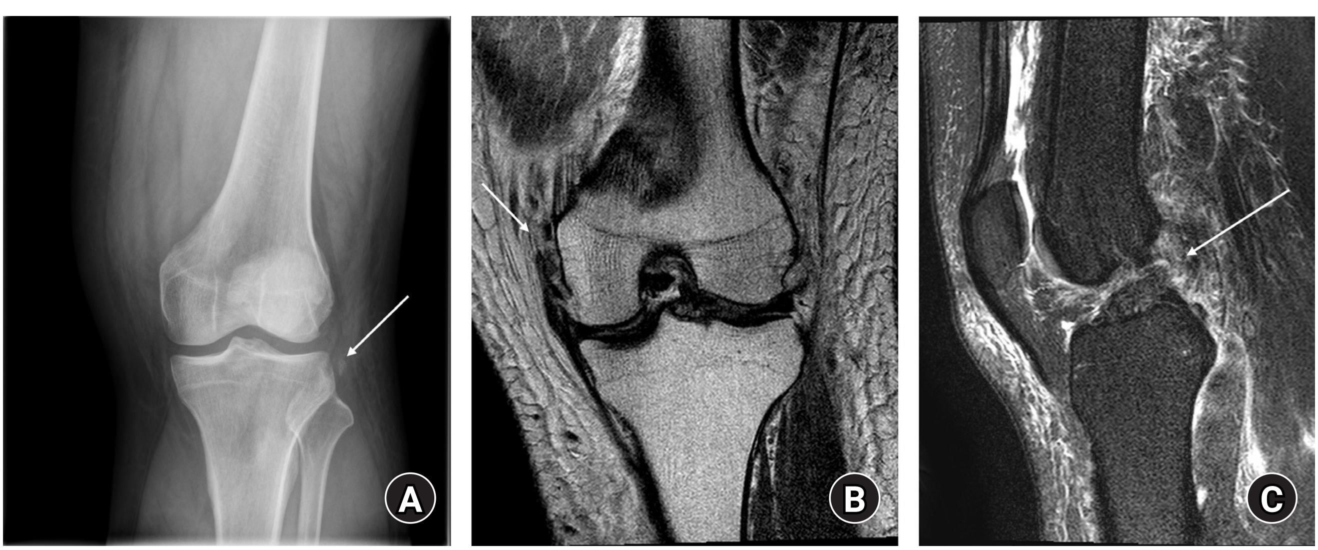

Fig. 3. A 29-year-old male patient was injured while skiing. (A) A Segond fracture (arrow) is observed on a knee anteroposterior radiograph. (B) An associated proximal medial collateral ligament rupture (arrow) is seen on the coronal T2-weighted magnetic resonance imaging (MRI), and (C) an anterior cruciate ligament rupture (arrow) is observed on the sagittal T2-weighted MRI.

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trauma patterns that typically combine varus stress with flexion and internal rotation. These injuries seldom present in isolation, frequently occurring in conjunction with ACL tears and patellar dislocation [45]. MRI is essential for diagnosis, offering detailed visualization of soft tissue and bony structures. Characteristic findings include ITB avulsion and retraction from Gerdy's tubercle, with distinctive fiber waviness [5]. Associated injuries, particularly ACL tears, are commonly identified during imaging. The optimal management of ITB injuries remains controversial, with no generally accepted treatment protocol. A case report suggests nonoperative treatment of ITB avulsion fractures may cause persistent knee joint instability [46] and are frequently associated with concomitant ligamentous damage. Severe ITB injuries likely require surgery to restore stability and address associated pathology [47]. Success depends on understanding both the complex anatomy and unique injury mechanisms involved.

Medial Collateral Ligament Avulsion Fracture

The medial collateral ligament (MCL) consists of two distinct components: the robust superficial MCL (sMCL) and the thinner deep MCL (dMCL) [48]. The sMCL provides primary restraint against valgus stress and internal rotation during knee flexion, while offering secondary stabilization against sagittal plane motion. The dMCL functions as a secondary valgus restraint, particularly in knee extension. Although sMCL injuries commonly occur at the proximal attachment to the medial femoral condyle, distal injuries may also be present. Avulsion fractures represent an uncommon injury pattern where ligamentous traction results in osseous fragment separation at the attachment site. These injuries occur at either the dMCL tibial insertion (reverse Segond fracture) or MCL femoral attachment (Stieda fracture), with the latter initially described by Dr. Alfred Stieda in 1908 [49]. Hall and Hochman [50] first characterized the reverse Segond fracture in 1997, alternatively termed medial Segond fracture. This injury pattern represents a medial tibial plateau avulsion fracture frequently associated with PCL and medial meniscal injuries. The condition typically results from high-energy knee trauma, predominantly affecting young adults. Subsequent research has demonstrated associations with ACL and MCL injuries [51]. Stieda fractures primarily involve the dMCL meniscofemoral fibers, potentially affecting adjacent retinacular structures or the posteromedial oblique ligament, with frequent concomitant ACL, PCL, and meniscal injuries [48]. Early surgical intervention for Stieda fractures is typically recommended in the presence of associated ligamentous injuries [52,53]. Small avulsion fragments in reverse Segond fractures generally do not require fixation. However, surgical fixation becomes necessary when large fragments compromise anteromedial knee stability or meniscal function [54,55]. In the absence of associated injuries, management parallels that of MCL injuries. Conservative treatment remains viable for grades I, II, and select grade III injuries (Fig. 4). Surgical intervention is indicated for isolated grade III MCL tears demonstrating significant valgus malalignment or MCL entrapment over the pes anserinus (Stener lesion), or when intra-articular or bony avulsion is present. Consequently, avulsion fractures with grade III instability may necessitate acute surgical repair.

Arcuate Ligament Avulsion Fracture

The “arcuate sign” presents as a fibular head avulsion fracture detected on knee radiographs, characterized by a horizontally-oriented elliptical osseous fragment on anteroposterior imaging, indicating posterolateral corner (PLC) pathology [56,57]. The PLC comprises multiple anatomic structures: the lateral collateral ligament, biceps femoris tendon, popliteus tendon, and arcuate complex. The arcuate complex consists of three distinct components: the popliteofibular ligament, arcuate ligament, and fabellofibular ligament [58].

This injury pattern typically results from either anteromedial knee trauma combined with tibial external rotation, or hyperextension forces with associated tibial internal rotation. The resultant avulsion fractures most commonly involve the fibular attachment site. Posterolateral corner injuries rarely present in isolation, frequently occurring in conjunction with ACL, PCL, or combined ligamentous pathology (Fig. 5) [59,60]. Although radiographs effectively demonstrate fracture morphology, MRI enables comprehensive evaluation of concomitant soft tissue injuries. MRI demonstrates characteristic bone marrow edema of the fibular styloid process on T2-weighted and short-tau inversion recovery sequences. This imaging modality facilitates

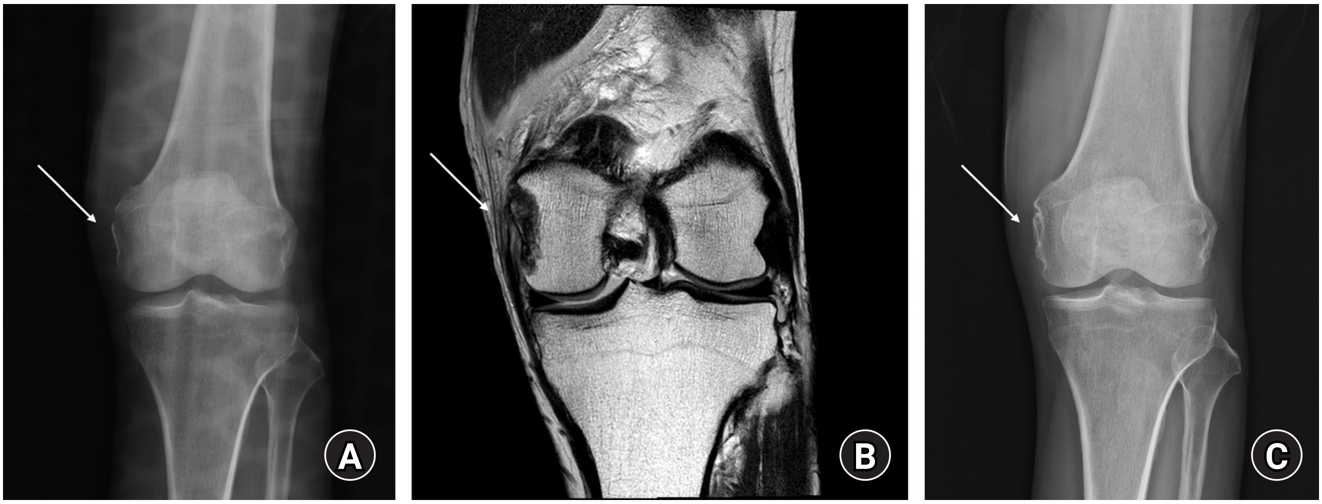

Fig. 4. (A) A 50-year-old male patient was injured in a pedestrian traffic accident, and a Stieda fracture (arrow) is observed on an anteroposterior radiograph. (B) On coronal T2-weighted magnetic resonance imaging, the medial collateral ligament continuity is intact, and there is no displacement of the Stieda fracture (arrow). (C) Bone union (arrow) was confirmed after 6 months of conservative treatment.

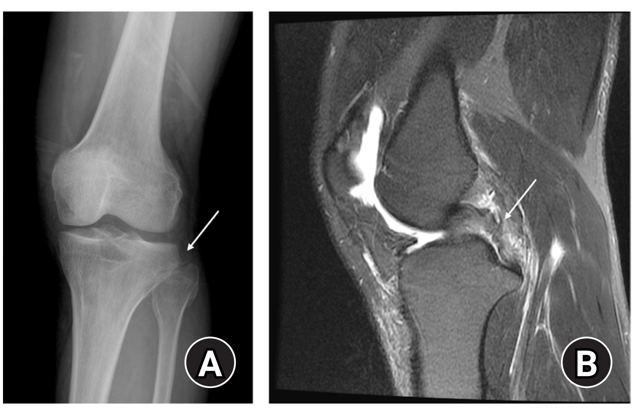

Fig. 5. A 37-year-old male patient was injured in an in-car traffic accident. (A) The arcuate sign (arrow) is observed on a plain anteroposterior radiograph. (B) Sagittal T2-weighted magnetic resonance imaging showed an accompanying posterior cruciate ligament rupture (arrow).

evaluation of fracture fragment morphology and associated soft tissue pathology involving the popliteofibular ligament, arcuate ligament, fibular collateral ligament, and biceps femoris tendon [57].

Conservative management remains the primary treatment approach for grade I-II PLC injuries [61], while surgical intervention may be indicated for grade III injuries [62]. The current literature on avulsion fracture fixation techniques remains limited, though various surgical methods have been described, including K-wire fixation, hook plate application, and suture anchor placement [63-66]. Given the frequent occurrence of concomitant injuries, thorough diagnostic evaluation and patient-specific treatment strategies remain essential for optimal outcomes.

Medial Patellofemoral Ligament Avulsion Fracture

The medial patellofemoral ligament (MPFL) functions as the principal ligamentous restraint against lateral patellar displacement and commonly injured during acute patellar dislocation [67,68]. Previous studies indicate that 40%-90% of MPFL disruptions occur at the femoral attachment site [69,70]. Known risk factors for patellar dislocation include anatomical variants such as trochlear dysplasia, increased tibial tubercle-trochlear groove distance, and patella alta [71]. Given the high prevalence of associated pathology, MRI evaluation is indicated for all acute patellar dislocation cases [69]. MPFL injuries demonstrate characteristic MRI findings including medial patellar margin osseous fragments or MPFL fiber disruption near the patellar attachment. Infrequently, these injuries may present with osteochondral avulsion fracture of the medial patellar margin [68]. Current literature suggests no significant advantage of surgical intervention over conservative management

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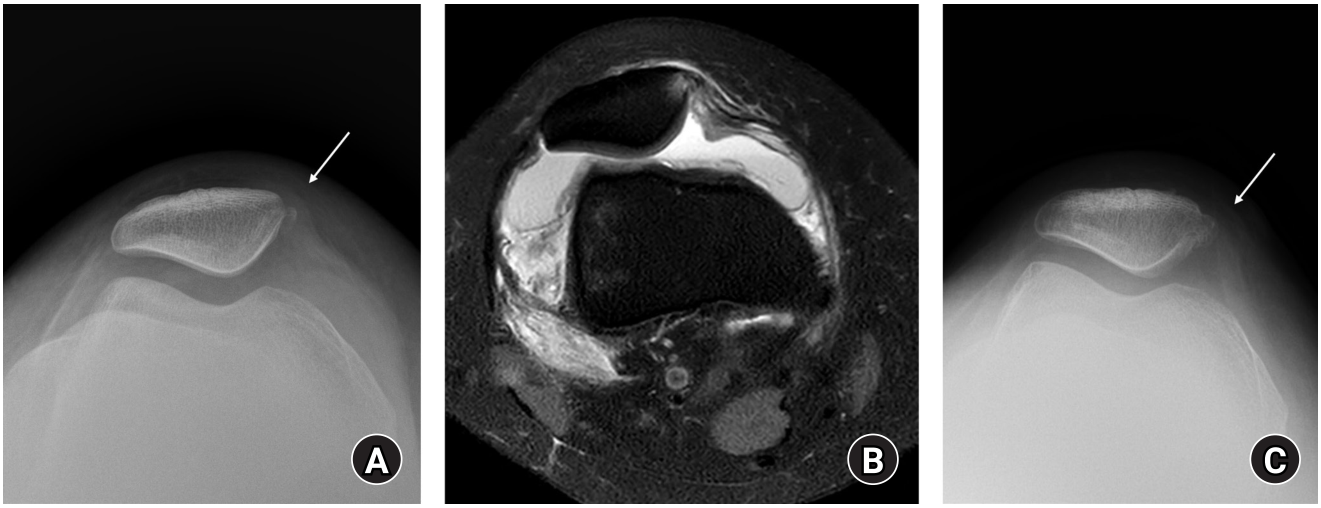

Fig. 6. (A) In an 18-year-old female patient with a patella dislocation, a medial patellofemoral ligament avulsion fracture (arrow) is observed on a knee merchant radiograph. (B) The displacement is minimal, and no chondral injury is observed. (C) Bone union (arrow) was achieved after 6 months of conservative treatment.

for primary patellar dislocations (Fig. 6) [72-74]. However, primary repair should be considered for femoral-sided avulsion fractures due to instability risk [70]. Additionally, surgical intervention may be indicated for patellar osteochondral avulsion fractures to maintain articular congruity [68].

Patella Tendon, Quadriceps Tendon Avulsion Fracture

The patella functions as a crucial osseous component in the articulation between quadriceps and patellar tendons, facilitating knee extensor mechanism leverage [75]. Patellar avulsion fractures occur less frequently than other patellar fracture patterns, predominantly affecting adolescent and young adult males due to their increased ratio of musculotendinous strength relative to osseocartilaginous structures [76,77]. The characteristic injury mechanism involves rapid quadriceps contraction during knee flexion. Clinicians should suspect this injury in patients who present with anterior knee trauma and inability to actively extend the knee following flexion trauma or falls [75]. Although structures such as the ITB and adductor muscles may permit partial knee extension, patellar avulsion fracture should be still considered when extension deficit is present [78]. MRI provides optimal diagnostic utility as conventional radiographs may fail to demonstrate small osseous fragments [79]. Nondisplaced fractures with preserved extensor mechanism integrity may be amenable to conservative management [3,5]. Conversely, displaced fractures indicating extensor mechanism disruption necessitate surgical intervention. Various surgical techniques enable anatomic reduction and stable fixation, including tension band wiring, transosseous sutures, intraosseous anchor sutures, and wire fixation, with technique selection guided by osteochondral fragment characteristics [76,77,79].

Conclusions

Avulsion fractures of the knee present with diverse patterns determined by the specific injury mechanism. The injury spectrum ranges from isolated minor fractures to complex multi-ligamentous injuries, with avulsion fractures frequently representing one component of broader injury patterns. Given the high prevalence of concomitant structural damage, MRI evaluation should be performed when avulsion fractures are suspected or diagnosed radiographically. Treatment strategies require individualization based on the comprehensive assessment of associated injuries.

Article Information

Author contributions

Conceptualization: SL, HKS. Investigation: JHK, SS, SL. Methodology: HKS. Supervision: HKS, WTC, SL. Writing-original draft: JHK, HKS, WTC, SS, SL. Writing-review & editing: JHK, HKS, WTC, SS, SL. All authors read and approved the final manuscript.

Conflict of interests

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Data availability

Not applicable.

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