



Review Article

Emerging trends and evidence-based approaches in the management of partial anterior cruciate ligament tears: A narrative review

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ABSTRACT

Partial anterior cruciate ligament (ACL) tears account for 10–27% of isolated ACL injuries and present diagnostic and therapeutic challenges due to their variable presentation and risk of progression. This narrative review aimed to synthesize evidence-based approaches to managing partial ACL tears through emerging biologic therapies and selective reconstruction techniques. A partial ACL tear diagnosis requires clinical tests, including Lachman's test, pivot-shift tests, and the KT-1000 arthrometer, as well as imaging. The gold standard diagnostic tool is arthroscopy. Non-operative management using dynamic braces and rehabilitation suits low-demand patients, yet carries a high risk of progression to full ACL tears in active individuals. Biologic therapies, including platelet-rich plasma and mesenchymal stem cells, demonstrate promising results in preclinical studies but inconsistent outcomes in human trials. Managing partial ACL tears with minimally invasive approaches featured innovative options, including the healing response technique and scaffold-assisted repairs, such as bridge-enhanced ACL restoration. Selective bundle reconstruction repairs the partial tears, preserves remnant fibers, and improves proprioception and functional outcomes compared to complete ACL reconstruction. The management of partial ACL tears warrants case-specific approaches based on injury and patient factors. Although biologic and selective reconstruction techniques are promising, additional evidence from high-quality studies is needed to validate these approaches, refine them, and develop standardized protocols to optimize knee function.

Keywords: Anterior cruciate ligament, Biological therapy, Injuries, Mesenchymal stem cell, Platelet-rich plasma, Reconstruction, Tissue scaffolds, Transplantation

INTRODUCTION

Partial anterior cruciate ligament (ACL) tears occur when parts of the ACL are damaged but not completely torn.^[1] Partial ACL tears account for 10–27% of all isolated ACL injuries.^[2]

With a mean length of 31–38 mm,^[3] the ACL extends from the posterior part of the lateral femoral condyle to the anterior tibial intercondylar eminence.^[2] The ACL consists of two bundles: The anteromedial bundle (AMB) and the posterolateral bundle (PLB).^[2] From the femoral insertion site, the AMB fascicles start from the anterior proximal aspect and end in the anteromedial

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aspect of the tibial insertion point, whereas the PLB fascicles go from the femoral posterior-distal part and attach to the posterolateral aspect of the tibia.^[3] The middle genicular artery is the major blood supplier to the ACL, along with the inferior genicular arteries.^[3] The ACL is innervated by the posterior auricular branches of the tibial nerve and contains various receptors for proprioception.^[3]

The ACL is a crucial structure in maintaining knee joint stability. It constitutes almost 80% of the total restraining force against anterior tibial translation during 30–90° of knee flexion.^[4] The AMB is isometric in nature, as its length remains constant throughout the range of motion. The PLB is non-isometric.^[5] In knee flexion, the AMB tightens with minimal change in length while the PLB relaxes and becomes shorter. The opposite occurs in knee extension.^[5] The AMB carries more load when the knee is in deep flexion (>30°), while the PLB is under greater stress when closer to full extension (0–15°). Thus, partial ACL injuries are more likely to affect the AMB when they occur in knee flexion, and the PLB when they occur in knee extension.^[5]

Episodes of instability, pain, and hemarthrosis are characteristic findings in partial ACL injuries, accompanied by a degree of functional impairment.^[6] Progression to a complete ACL tear is a possible complication, with key risk factors including a partial ACL injury at a young age (<35 years), a body weight above 90 kg, a height exceeding 1.83 m, a high body mass index, and participation in high-impact sports.^[7] Furthermore, damaging more than 50% of the ACL or injury to the PLB are risk factors for progression.^[5,6]

Partial ACL tears remain a diagnostic and therapeutic challenge, conventionally managed through conservative rehabilitation or complete ACL reconstruction when instability is evident. However, recent advances in biologic augmentation and selective reconstruction techniques have shifted the focus toward preserving native ligament fibers and enhancing intrinsic healing. This narrative review summarizes current knowledge and highlights emerging approaches, aiming to provide clinicians with an updated evidence-based overview of evolving management strategies for partial ACL tears.

MATERIALS AND METHODS

Relevant literature was identified through PubMed and Google Scholar databases using keywords such as “partial ACL tear,” “selective reconstruction,” “biologic therapy,” “PRP,” “mesenchymal stem cells,” and “scaffold-assisted repair.”

In an effort to minimize potential selection and confirmation bias, all literature searches and screening were conducted independently by multiple authors. The review included relevant clinical, preclinical, and biomechanical studies,

incorporating both supportive and conflicting evidence to provide a balanced overview. Conclusions regarding individual techniques were drawn from the overall weight of the available evidence. As a narrative review, formal inclusion/exclusion criteria and quantitative synthesis were not applied. This approach was chosen to facilitate discussion of emerging techniques that are not yet suitable for systematic analysis.

DIAGNOSIS AND EVALUATION

Diagnosis of partial ACL tears is challenging and requires a multimodal approach [Table 1].^[6] Clinical examination can help in assessing ACL integrity. Partial ACL tears usually exhibit a positive Lachman’s test with a firm endpoint.^[8] Moreover, a pivot-shift test with 0 or + 1 grades is suggestive of partial tears, while higher grades lean more toward complete ruptures.^[9] To increase the sensitivity, it is better to perform a pivot-shift test under general anesthesia to evaluate the functional status of the intact fibers.^[7]

The KT-1000 arthrometer (KT-1000) is a quantitative test used to compare measurements of the anterior tibial translation in both limbs. A difference of <3 mm is considered normal, whereas a 3–5 mm difference is suggestive of a partial ACL tear. The inability to assess rotational instability is a limitation of this test, necessitating a multimodal approach for a definitive diagnosis.^[7]

The most suitable imaging modality for partial ACL tears is magnetic resonance imaging (MRI). A partial tear is suspected if MRI shows a T2-weighted hyperintense signal with a thickened ligament, fiber laxity, and ACL bowing. In addition, the presence of continuous ACL fibers on MRI suggests an incomplete tear.^[10]

MRI is reliable for diagnosing complete ACL tears; however, it has limitations in detecting partial tears due to the difficulty in identifying the correct imaging slices and distinguishing partial tear patterns from other ACL-related injuries.^[8] MRI

Table 1: Diagnostic modalities for partial ACL tears.

Modality	Key features
Lachman/ Pivot-shift	(Lachman) Firm endpoint; (Pivot-shift) grade 0/+1 indicates partial tear, more sensitive under anesthesia
KT-1000	3–5 mm difference suggests partial tear; does not assess rotation
MRI	T2 hyperintense, thickened ligament, fiber laxity; limited in partial tears
Arthroscopy	Gold standard; direct visualization and classification; invasive

KT-1000: KT-1000 Arthrometer, MRI: Magnetic resonance imaging, T2: T2-weighted MRI sequence, ACL: Anterior cruciate ligament

demonstrates only moderate diagnostic accuracy for partial ACL tears, with sensitivity between 40–75% and specificity between 50% and 90%.^[11] The higher-resolution 3 Tesla MRI model has achieved better results, with 77% sensitivity and 97% specificity.^[12]

The gold standard method for diagnosing a partial ACL tear is arthroscopy. It should be implemented whenever the findings support the diagnosis or are inconclusive. Arthroscopy can detect the extent and location of the injury, aid in classification, and ultimately direct the appropriate treatment.^[6] Dejour *et al.*^[9] classified ACL tears arthroscopically into four categories [Figure 1]: Complete ACL tear, AMB intact, PLB intact, and partial tears healing through the posterior cruciate ligament. They further categorized tears based on the functional status of the remaining fibers as either functional or non-functional, which helps plan treatment and differentiate them from complete ACL tears.^[9]

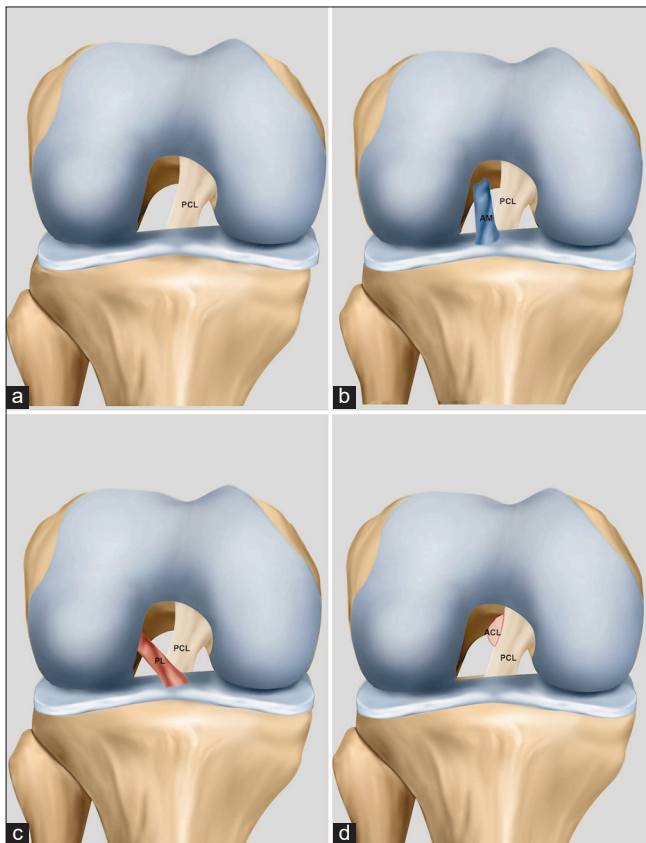


Figure 1: Classification of (ACL) Anterior cruciate ligament tears according to Dejour *et al.*, 2013. This figure illustrates the four classes of ACL tears. (a) Complete ACL tear, (b) AM bundle intact, (c) PL bundle intact, (d) Partial tear healing via the PCL. ACL: Anterior cruciate ligament, PCL: Posterior cruciate ligament, AM: Anteromedial bundle, PL: Posterolateral bundle.

NON-OPERATIVE MANAGEMENT

There is a wide array of treatment options for partial ACL tears. A conservative approach is indicated for patients with minimal physical activity or a low risk of progressing to a full ACL tear, as indicated by a negative pivot-shift test and <5 mm tibial anterior translation on the KT-1000.^[3,6] Knee mobility adjustment, through casts, splints, or braces, is crucial in the healing process. LaPrade *et al.* reported better treatment outcomes with dynamic braces than with static braces, as dynamic braces generate higher forces to stabilize the tibia after ACL injuries.^[6,13]

Shortly after the injury, it is better to have a detailed rehabilitation plan supervised by a specialized physiotherapist, including a period of immobilization followed by a 3-month program to increase strength and regain a full range of motion.^[3,14]

A systematic review of two randomized controlled trials involving 123 subjects with partial ACL tears found that Tai Chi (a traditional Chinese exercise with slow, flowing movements) improved pain, proprioception, and quadriceps strength, whereas Pilates (an exercise method focusing on core strength and flexibility) improved strength only. However, none of them improved functional outcome scores, indicating they are not substitutes for standard rehabilitation or surgical treatment.^[15]

A known complication of conservative treatment is the progression to a complete tear. A study by Rai *et al.*, of 351 young males found that 47% of conservatively treated partial ACL tears progressed to complete tears after an average follow-up of 17 months.^[7]

BIOLOGIC AND MINIMALLY INVASIVE TECHNIQUES

Platelet-rich plasma (PRP)

PRP is an important non-invasive treatment option for partial ACL tears. The combination of various platelets and growth factors in PRP helps initiate and promote tissue healing.^[8] Different growth factors, including platelet-derived growth factor, transforming growth factor B1 (TGF-B1), and vascular endothelial growth factor, play an important role in facilitating the healing of injured tissues, along with platelets' functions in aggregation and clot formation, which ultimately enhances the healing process.^[8]

In animal studies, the effect of PRP in partial ACL healing is promising. Li *et al.*, demonstrated that a thermosensitive hydrogel-PRP complex enhanced tissue repair and ACL strength in rats by upregulating growth factor expression^[16] and similar effects were seen in dogs.^[17] In a preclinical study, Andriolo *et al.*, reported improved histological

and biomechanical properties of tendinous grafts treated with PRP.^[18] However, human studies have yielded mixed outcomes. Zicaro *et al.*, evaluated 40 patients with partial ACL tears treated with PRP and reported a 32% failure rate at a mean follow-up of 25 months. No significant improvement was observed in return to sports, subjective outcomes, or MRI findings post-injection.^[19] While some clinical data suggest potential improvements in knee stability and functional scores,^[20] evidence in humans remains inconclusive, and further high-quality studies are needed.

Mesenchymal stem cells (MSCs)

Mesenchymal stem cells (MSCs) are another modality that showed promise in improving ACL healing in animal models. Various sources of MSCs, including bone marrow, ACL vasculature, tendons, and umbilical cords, have been shown to promote ACL healing.^[21] Given their nature, MSCs can differentiate into various progenitor cell types, promote angiogenesis, and enhance tissue healing.^[22] Jang *et al.* suggested that MSCs may restore normal ACL functional characteristics and aid graft healing in animal studies.^[23]

Healing response technique (HRT)

The healing response technique (HRT) is a minimally invasive procedure for treating proximal ACL tears. It involves creating a microfracture at the medial wall of the lateral femoral condyle, near the ACL footprint in the femur. This forms a blood clot and hematoma at the proximal ACL insertion, which aids in scar formation and healing.^[24]

Studies evaluating HRT for proximal ACL tears have shown mixed outcomes. Jorjani *et al.*, reported favorable short-term results in 43 of 126 patients, with high Lysholm and International Knee Documentation Committee (IKDC) 2000 scores and minimal joint instability, though 24.6% required later reconstruction.^[25] Steadman *et al.* found sustained improvements over 7.6 years in skeletally mature patients, with

only a 9% reconstruction rate and high satisfaction.^[26] However, Wasmaier *et al.* conducted a retrospective comparative study on 157 patients, including 30 treated with HRT and 127 managed conservatively, and found no significant advantage of HRT over conservative management in joint laxity, functional scores, or reconstruction rates.^[24]

Growth factor augmentation

Growth factors have shown promise in enhancing the healing of partial ACL tears in animal models. In a study on 36 rabbits, applying 4 ng of TGF- β 1 significantly improved the healing of injured ACLs.^[27] Furthermore, connective tissue growth factor (CTGF) enhanced ACL regeneration in rabbits, increasing collagen fiber density and fibroblast numbers and improving biomechanical properties compared with controls treated with fibrin glue only. After 2–6 weeks, the ACLs in the CTGF-treated group exhibited significantly higher maximum loads and stiffness than those in the control group.^[28] In a recently published case report, a 39-year-old male with a partial ACL tear was administered three intra-articular injections of activated growth factors (AGF) prepared using a proprietary protocol. Six months after AGF administration, the patient had minimal pain, with negative Lachman and anterior drawer tests, and a Lysholm score of 92.^[29]

Despite the promising potential for improving healing in the growth factor studies, further research with larger cohorts and long-term follow-up is needed to validate these techniques for clinical use.^[8] A summary of the main biologic modalities investigated for partial ACL healing and their reported outcomes is presented in Table 2.

SCAFFOLD-ASSISTED BIOLOGICAL REPAIR

Scaffolds are engineered artificial tissues designed to mimic the native physical, mechanical, and biological functions of

Table 2: Biologic modalities for partial ACL tears.

Modality	Representative studies	Key findings	Evidence level
Platelet-rich plasma	Andriolo <i>et al.</i> , ^[18] 2015 (preclinical graft), Xie <i>et al.</i> , ^[17] 2013 (dog), Li <i>et al.</i> , ^[16] 2020 (rat), Zicaro <i>et al.</i> , ^[19] 2021 (prospective comparative study)	Enhanced tissue repair and ligament strength in animals; mixed outcomes in humans with limited functional improvement and ~30% failure in one series	II–IV
Mesenchymal stem cells	Jang <i>et al.</i> , ^[23] 2015 (review article), Guo <i>et al.</i> , ^[21] 2018 (systematic review of animal trials), Rahyussalim <i>et al.</i> , ^[22] 2023 (review article)	Improved ligament healing in animal models and may enhance angiogenesis and graft integration, though human data remain limited	IV–V
Growth factor augmentation (TGF- β 1, CTGF, AGF)	Kondo <i>et al.</i> , ^[27] 2005 (rabbit), Sun <i>et al.</i> , ^[28] 2018 (rabbit), Hidayat <i>et al.</i> , ^[29] 2024 (case report)	Improved collagen organization and biomechanical strength in animals; early human data suggest pain and stability improvement	IV–V

TGF- β 1: Transforming growth factor beta 1, CTGF: Connective tissue growth factor, AGF: Activated growth factor, ACL: Anterior cruciate ligament

the tissue's extracellular matrix, thereby stimulating native tissue formation and facilitating cell migration.^[30] Ideal scaffolds have been described as those with a highly porous network, a controllable resorption rate, a surface suitable for cell migration, and mechanical properties that match those of native tissue.^[31] Their use can be of great benefit in regard to the healing capacity of an injured ACL and can help avoid the known disadvantages of classic surgical reconstruction.^[32]

Many studies combine scaffolds with various biologics and techniques to enhance their utility, with varying success.^[32] Bridge-enhanced ACL restoration, where a collagen-based scaffold is soaked in the patient's blood and combined with a suture repair, has demonstrated favorable outcomes in recent literature.^[33,34] In a contrasting case, wrapping an ACL autograft with an amniotic collagen matrix and injecting bone marrow aspirate showed no difference with controls who underwent classic surgical reconstruction in 2-year follow-up outcomes.^[35]

Scaffold-assisted ACL repair is a shift from mechanically replacing tissue to biologically restoring it. As continued clinical trials and technique refinements emerge, they are likely to play an increasingly significant role in the treatment of partial ACL tears. Further research is crucial to identify the optimal combinations of scaffolds, biologics, and patient factors that yield the most durable outcomes.

SURGICAL MANAGEMENT

Surgery, whether complete or selective reconstruction, is the cornerstone of management for partial ACL tears in non-functional knees.^[3] Sonnery-Cottet and Colombet proposed a treatment algorithm for partial ACL tears, where surgery is indicated for patients with differential laxity of more than 4 mm, or those with less than 4 mm but with a positive pivot-

shift on physical examination, and either young, physically active, or having extensive injury on arthroscopy.^[14] The definitive deciding factor in the surgical plan is arthroscopic evaluation to determine the extent of injury and the quality of the residual bundle.^[3,14,36] However, there remains no consensus on which type of procedure is ideal for partial ACL tears, and the wide array of patient and injury-specific factors can further complicate this issue.

Conventionally, full ACL reconstruction was the treatment of choice for partial ACL tears. Selective remnant-preserving reconstruction was perceived as a novel procedure with limited advantages. A study by Park *et al.* in 2012 compared remnant-preserving augmentation with double-bundle reconstruction in 100 patients with a minimum 2-year follow-up and found no significant differences in terms of post-operative range of motion, Lachman and pivot-shift tests, Visual Analog Scale scores, Lysholm scores, Tegner scores, and IKDC scores, with only slightly better anterior drawer results in the augmentation group.^[37] Similar results were reported by Pujol *et al.* at 1-year follow-up.^[38]

Recent literature, on the other hand, has highlighted the advantages of selective reconstruction as the preferred approach. Proprioception is enhanced by leaving the native bundle fibers.^[39] Mechanically, the intact fibers can help add strength postoperatively, as shown by Pujol *et al.*^[38] The blood supply is also better maintained when leaving the residual bundle, helping solve a known challenge in the healing power of the ACL.^[40] In a meta-analysis by Won *et al.*, remnant-preserving procedures yielded statistically significant improvements in arthrometric evaluation and functional scores compared to their non-preserving counterparts.^[41]

Studies have demonstrated favorable functional outcomes, with one reporting that 76% of patients returned to their

Table 3: Comparative and outcome studies of remnant-preserving ACL reconstruction.

Study	Design/comparison	Main findings	Evidence level
Park <i>et al.</i> , 2012 ^[37]	Prospective case series (100 patients); remnant-preserving augmentation versus double-bundle reconstruction	No significant differences in ROM or functional scores; anterior drawer test slightly favored remnant-preserving group	IV
Pujol <i>et al.</i> , 2012 ^[38]	Prospective randomized study (54 patients); selective AM-bundle versus single-bundle reconstruction	Comparable short-term results; better control of anterior laxity with remnant preservation	I
Won <i>et al.</i> , 2020 ^[41]	Systematic review and meta-analysis (5 RCTs+6 observational); remnant-preserving versus conventional reconstruction	Statistically significant improvement in arthrometric and functional scores with remnant-preserving techniques	I
Carulli <i>et al.</i> , 2020 ^[36]	Retrospective case series (36 patients) undergoing selective single-bundle reconstruction	Significant improvement in IKDC, KOOS, and KT-2000 scores; 91.6% returned to preinjury sport level within 5.1 months; no complications reported	IV

ROM: Range of motion, AM: Anteromedial, RCT: Randomized controlled trial, IKDC: International knee documentation committee, KOOS: Knee injury and osteoarthritis outcome score, KT-2000: KT-2000 arthrometer, ACL: Anterior cruciate ligament

preinjury level of activity at 3-year follow-up.^[42] In a study by Carulli *et al.*,^[36] 33 of 36 patients returned to their preoperative level of sports activity at a mean of 5.1 months after selective reconstruction. Selective reconstruction has also been shown to be effective, independent of the specific technique or graft type.^[36] A summary of key comparative and outcome studies evaluating remnant-preserving ACL reconstruction is presented in Table 3.

This review has certain limitations. Being a narrative review, it is inherently subject to selection and interpretation bias, and it does not provide the comprehensive coverage or methodological rigor of a systematic review. Furthermore, much of the cited evidence comes from small clinical series, retrospective studies, or preclinical models, which limits the strength and generalizability of the conclusions. These factors should be considered when interpreting the findings of this review.

CONCLUSION

Management of partial ACL tears is shifting towards a more individualized approach that considers injury and patient-specific factors. Diagnosis is guided by clinical tests and imaging, but arthroscopy remains the gold standard. Selective reconstruction is an increasingly favored technique in which remnant fibers are preserved to enhance proprioception and stability, resulting in better functional outcomes than traditional reconstruction. Biological and minimally invasive strategies, including PRP, MSCs, and scaffold-assisted repairs, show promise in early trials.

Recommendations

Integration of these novel options into standard clinical practice is currently limited by the lack of robust, long-term human data. Future research should focus on larger clinical trials to validate these emerging techniques and establish standardized protocols to optimize patient outcomes.

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