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Aims & Scope

Sports Traumatology and Arthroscopy is an international, peer-reviewed journal dedicated to the latest advances and research in sports traumatology, arthroscopy and related surgical techniques. Our aim is to serve as a premier platform for the dissemination of significant new findings and the exchange of evidence-based knowledge and experience that highlight progress in all areas of sports traumatology and arthroscopy. Three issues are released every year in April, August, and December.

Aim

The primary aim of Sports Traumatology and Arthroscopy is to improve the care of patients with sports injuries by promoting the understanding of the pathophysiology of sports injuries, improving diagnostic techniques, and advancing treatment and rehabilitation methods. The journal aims to bridge the gap between sports traumatology research and clinical practice by providing a forum for the exchange of information relevant to clinical orthopedics, sports medicine and the science of sports injury and repair.

Scope of the Journal

The scope of the journal includes, but is not limited to, the following areas

Arthroscopy: Innovative techniques, clinical outcomes, and advances in arthroscopic surgery for the treatment of sports injuries.

Sports Orthopedics: Articles on surgical and non-surgical treatment options for sports injuries, including the use of novel techniques, materials, and implants.

Injury Prevention and Management: Studies on the prevention, diagnosis, treatment, and rehabilitation of sports-related injuries.

Regenerative Medicine: Treatment methods that involve the process of replacing, engineering, or regenerating human cells, tissues, or organs to restore or establish normal function after sports injuries, including ligaments, cartilage, menisci, and bone.

Biomechanics and Kinesiology: The study of the biomechanics of exercise and its effects on the body, with the goal of improving injury prevention strategies and rehabilitation approaches.

Rehabilitation and Physical Therapy: Evidence-based practices for rehabilitating athletes after injury or surgery, including physical therapy techniques and recovery protocols.

Performance Enhancement: Studies on optimizing athletic performance through innovative training techniques, nutrition, and injury prevention strategies.

Musculoskeletal Anatomy: Studies that focus on the anatomical and biomechanical aspects of sports injuries in order to develop better prevention and treatment strategies, such as new surgical techniques and modifications.

Diagnostic Techniques and Imaging: Research on imaging and diagnostic techniques for sports injuries.

Systematic Review and Metanalysis: Comprehensive reviews of the current literature that use explicit, systematic methods to identify, select, and critically appraise relevant research on a specific topic or question.

Case Reports: Detailed reports of individual cases, clinical experiences, and studies that contribute to the understanding of sports injuries and their management.

Sports Traumatology and Arthroscopy invites submissions from researchers, clinicians, and allied health professionals in sports medicine, orthopedic surgery, physical therapy, and related fields. We are committed to providing our readers with high-quality, impactful articles that contribute to the advancement of sports traumatology, arthroscopy, and injury management. Through rigorous peer review and a commitment to excellence, we aim to assist orthopedic surgeons and all physicians who care for patients with sports injuries in improving patient outcomes and advancing the field of sports traumatology and arthroscopy.

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Declarations

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Preparation of Declarations in the Abstract Page

Acknowledgements

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References

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Style and Format

Reference citations in the text should be identified by numbers in square brackets, such as [5], [7,8], and [4-9, 11]. The reference list should be numbered consecutively.

Journal Article

Grimberg J, Duranthon LD, Bellaïche L, Petrover D, Kalra K. The time for functional recovery after arthroscopic rotator cuff repair: Correlation with tendon healing controlled by computed tomography arthrography. Arthroscopy. 2008;24:25-33.

If there are more than 6 authors, provide first six authors and use 'et al.' at the end of author list. Digital Object Identifier (doi) number should be added to the end of the reference (if available).

Cvetanovich GL, Gowd AK, Liu JN, Nwachukwu BU, Cabarcas BC, Cole BJ, et al. Establishing clinically significant outcome after arthroscopic rotator cuff repair. J Shoulder Elbow Surg. 2019;28:939-48.

Book

Newton ML. Current practice of pain. 1st ed. St. Luis, MO: Mosby; 1990.

Book Chapter

Jurkovich GJ. Duodenum and pancreas. In: Mattox KL, Feliciano DV, Moore EE, editors. Trauma. 4th ed. New York: McGraw-Hill; 2000. pp. 735-62.

Online Document

Cartwright J. Big stars have weather too. IOP Publishing PhysicsWeb. http://physicsweb.org/articles/news/11/6/16/1. Accessed 26 June 2007.

Dissertation

Trent JW. Experimental acute renal failure. Dissertation, University of California; 1975.

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Editorial

From Posterior Tibial Slope to Sagittal Knee Phenotypes: Personalizing ACL Surgery

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Anterior cruciate ligament (ACL) reconstruction has traditionally been approached as a soft-tissue solution to a ligament injury. The surgeon selects a graft, restores the anatomical footprints, secures fixation, addresses associated meniscal pathology, and guides the patient through rehabilitation. Nevertheless, graft failure and residual instability continue to occur despite technically satisfactory reconstruction. Contemporary ACL surgery is therefore moving beyond standardized reconstruction toward individualized risk stratification, graft selection, alignment assessment, augmentation, and rehabilitation.[1]

Posterior tibial slope (PTS) has become one of the most recognizable anatomical factors within this framework. A steeper tibial plateau increases the anterior shear generated during axial loading, promoting anterior tibial translation and increasing the mechanical demand on the native ACL or reconstructed graft.[2,3] Clinical evidence has consistently associated elevated PTS with ACL injury and reconstruction failure, with 12° frequently used as a high-risk radiographic threshold.[2,3] A recent review comprehensively summarized the measurement, biomechanics, indications, techniques, and outcomes of PTS-modifying osteotomies.[2] Rather than repeating that technical account, the present editorial addresses the next question: How should PTS be incorporated into personalized ACL surgery?

Greater recognition of PTS creates a new danger: replacing one oversimplification with another. ACL surgery should not evolve from performing the same reconstruction in every patient to performing an osteotomy whenever the slope exceeds a numerical threshold. A PTS of 12° is an important warning sign, but it is not, by itself, a diagnosis, an automatic surgical indication, or a universal correction target. The first challenge is measurement. PTS values vary according to imaging modality, tibial reference axis, plateau selection, visualized tibial length, and radiographic rotation.[2,3] Magnetic resonance imaging permits separate medial and lateral measurements but commonly references only the proximal tibia and may produce values that differ substantially from radiographic measurements. Thresholds established on lateral radiographs, therefore, cannot be directly transferred to magnetic resonance imaging or computed tomography. For clinical decision-making, PTS should be assessed on a strict lateral radiograph that adequately visualizes the proximal tibial shaft, preferably at least 15 cm. A consistent proximal anatomical axis and the medial tibial plateau should be used as the radiographic references.[2,3] Without methodological standardization, differences between 11°, 12°, and 13° may reflect technique rather than biology.

Risk also exists along a continuum. Radiographic medial PTS differentiated

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successful primary reconstruction from multiple-revision ACL reconstruction more effectively than magnetic resonance imaging-based medial or lateral measurements. A radiographic medial PTS of at least 16° was associated with an approximately threefold increase in the odds of multiple revisions.[6] This does not establish 16° as a universal osteotomy threshold. Rather, increasingly extreme radiographic values identify increasingly hostile sagittal anatomy and should prompt more comprehensive assessment. Importantly, PTS may not always be a fixed constitutional characteristic. In skeletally immature patients with ACL injury, PTS can change during growth over long-term follow-up, a developmental observation that should not be extrapolated directly to adults.[4] Separately, in skeletally mature patients undergoing revision ACL reconstruction, radiographic medial PTS increased by a mean of 1.1° over approximately 9 years, with progression greater than 2° in one-quarter of patients; posterior medial meniscal resection was more frequent in this subgroup.[5] Although these distinct studies do not establish causality, together they challenge the assumption that PTS is invariably immutable. In selected adult revision knees, particularly those with recurrent instability and posterior medial meniscal loss, increasing PTS may represent a progressive sagittal deformity rather than simply the upper end of constitutional variation.

The second challenge is determining whether the anatomical risk factor has become functionally expressed. Two patients with the same PTS may demonstrate markedly different sagittal knee mechanics. One may maintain a relatively centered tibiofemoral resting position through intact menisci, preserved secondary stabilizers, constitutional soft-tissue stiffness, and neuromuscular control. Another may demonstrate substantial anterior tibial subluxation because the same osseous geometry is combined with chronic ACL deficiency, meniscal loss, hyperlaxity, or previous failed reconstructions. Static anterior tibial translation (sATT), assessed on a strict monopedal weight-bearing lateral radiograph, provides a measure of this functional expression. Unlike manual or instrumented laxity testing, which evaluates displacement under an externally applied force, sATT describes the tibia's position relative to the femur under physiological axial loading. It therefore represents the functional sagittal set-point produced by the combined effects of osseous geometry, ligamentous restraint, meniscal competence, soft-tissue compliance, neuromuscular control, hyperlaxity, and injury chronicity.[7]

Importantly, sATT is not merely another term for passive anterior laxity, nor should it be assumed to normalize after an otherwise successful ACL reconstruction. In same-patient measurements, ACL reconstruction reduced stress-induced anterior tibial translation from approximately 7–8 mm to 3–4 mm, whereas monopedal sATT remained essentially unchanged.[8] ACL reconstruction may therefore restore the passive displacement envelope without necessarily recentering the tibia to a normal resting position under physiological load. This distinction has important clinical consequences. Excessive weight-bearing anteriorization has been associated with ACL reconstruction failure, and recent studies have shown that elevated sATT remains associated with graft rupture even after lateral extra-articular tenodesis.[7,9,10] In a cohort with a minimum follow-up of 6 years, the graft-rupture rate was 19.4% among patients with PTS>12°, compared with 2.7% among those with PTS<12°. The highest rupture rate, 26%, occurred when PTS of at least 12° was combined with sATT of at least 5 mm.[9] In a larger contemporary cohort, patients sustaining graft rupture similarly demonstrated greater PTS and sATT than those without rupture.[10] These findings indicate that a reconstructed graft may remain exposed to an unfavorable weight-bearing sagittal set-point, even with restoration of conventional clinical stability. Instrumented laxity, stress-induced translation, and monopedal sATT should therefore be regarded as related but non-interchangeable measurements. The first two describe how far the tibia can be displaced; sATT describes where it rests when the limb accepts physiological load.

Elevated sATT may arise through at least three mechanisms. Osseous anteriorization is driven by a constitutionally steep or progressively increased PTS that continuously biases the tibia anteriorly. Acquired soft-tissue anteriorization develops through chronic ACL deficiency, posterior meniscal loss, repeated graft failure, and progressive insufficiency of the secondary stabilizers. Inherent soft-tissue anteriorization occurs in constitutionally hyperlax patients who may demonstrate high bilateral sATT without substantial pathological side-to-side asymmetry.[7] These mechanisms may converge on a similar radiographic appearance but require different treatment strategies. A unilateral, slope-driven anteriorized knee is not equivalent to symmetric bilateral anteriorization in a hyperlax patient. Likewise, a knee with moderate PTS but marked sATT after medial meniscal deficiency may be more compromised than a knee with a steeper slope but preserved meniscal containment.

Meniscal status is therefore a critical modifier. The meniscus should not be regarded merely as an associated lesion documented during arthroscopy; it is an essential component of sagittal stability. Biomechanical evidence indicates that ACL reconstruction combined with complete ramp repair may restore anterior translation across a range of PTS values. In contrast, following substantial medial meniscal deficiency, isolated ACL reconstruction may fail to restore normal translation at steeper slopes, and concomitant slope correction

may become necessary.[11] Meniscal loss may therefore act as a biomechanical multiplier, converting tolerable osseous morphology into sagittal decompensation.

Several frameworks have attempted to move decision-making beyond isolated PTS thresholds. Ollivier et al. introduced the ACL + Slope Tracing Risk-Factor Algorithm (A+STRA) score, integrating previous revisions, meniscal deficiency, anatomical factors, and potential limitations to slope correction through weighted scoring.[12] This was an important attempt to incorporate the broader clinical context. However, its prescriptive arithmetic may suggest greater precision than is currently supported, particularly because biologically interdependent factors cannot necessarily be treated as independently additive. Schuster et al. approached the same problem through the Avalanche Concept, appropriately emphasizing that recurrent ACL failure usually results from an accumulation of interacting risk factors rather than from a single isolated measurement.[13] Its individualized philosophy is compelling, although the concept remains abstract and does not provide an objective method for quantifying sagittal decompensation or determining a patient-specific correction target.

The Assessment-Led Personalization (ALP) system offers a complementary, assessment-led framework for individualized decision-making.[14] It combines bilateral monopedal sATT, normalized sATT percentage, side-to-side sATT asymmetry, PTS laterality, meniscal status, injury chronicity, generalized hyperlaxity, and recurvatum to identify the dominant mechanism of sagittal anteriorization. Rather than deriving surgical necessity from a rigid point total, the ALP system uses the weight-bearing sagittal set-point to determine whether osseous morphology has become functionally expressed. The assessment applies to both primary and revision ACL reconstruction. Although overt sagittal decompensation is more commonly encountered in knees with markedly elevated PTS or after previous reconstruction, neither revision status nor an isolated slope threshold constitutes an indication for slope correction. Selected primary cases may already demonstrate an unfavorable combination of excessive PTS, pathological unilateral sATT, meniscal deficiency, and other evidence of sagittal decompensation. Within this framework, the contralateral knee serves as an internal reference rather than an unquestioned normal control. Bilateral differences in PTS and sATT should be considered while accounting for constitutional laterality and generalized hyperlaxity. Normalization of sATT to the sagittal dimension of the medial tibial plateau helps reduce magnification-related variability, while adjustment for PTS asymmetry may help distinguish osseous laterality from acquired soft-tissue decompensation.[14]

The operative strategy should follow the dominant pathology rather than the highest numerical measurement. A patient with moderately increased PTS, a centered weight-bearing sagittal position, intact menisci, and no generalized laxity may reasonably undergo isolated anatomical ACL reconstruction. A hyperlax patient with symmetric bilateral anteriorization may benefit more from graft optimization and selective extra-articular augmentation than from osseous correction. Conversely, a patient with elevated PTS, pathological unilateral sATT, chronic posterior meniscal deficiency, progressive slope, or repeated atraumatic graft failure may require slope-reducing osteotomy in addition to ligament reconstruction. Slope-reducing osteotomy is a powerful intervention, but the expanding recognition of sagittal risk should not justify indiscriminate expansion of its indications. Current clinical evidence is encouraging but remains predominantly retrospective.[2,3] The decision to correct the slope should therefore reflect the interaction between anatomy, weight-bearing sagittal position, meniscal competence, laxity phenotype, previous failures, and the expected demands on the reconstructed graft.

Correction must also remain proportional. The ideal postoperative PTS is unlikely to be identical in every knee. Planning should account for preoperative PTS, weight-bearing anteriorization, constitutional recurvatum, posterior cruciate ligament function, meniscal status, cartilage condition, coronal alignment, osteotomy level, and intended correction angle.[2,3,7,14] Wedge height should similarly not be selected through a universal millimeter-per-degree rule. The required resection depends on the individual osteotomy depth and planned correction angle. A depth-based planning method has demonstrated greater precision than fixed millimeter-per-degree ratios, which may produce clinically relevant undercorrection or overcorrection.[15] The correction angle should remain the principal target; wedge height is a patient-specific and technique-specific consequence of that target. Overcorrection may create a new biomechanical problem while attempting to solve the original one. Undercorrection may leave the graft exposed to the same anterior shear environment that contributed to failure. The objective should not be to produce a radiographically "normal" value at any cost, but to achieve sufficient sagittal recentering without creating an abnormal posteriorly directed knee phenotype.

Personalization in ACL surgery has often focused on graft choice, tunnel placement, lateral extra-articular procedures, rehabilitation, and return-to-sport testing.[1] Sagittal alignment adds another essential dimension. The clinically relevant questions are no longer limited to whether PTS is increased. How was it measured? Is it constitutional, growth-related, or progressively acquired? Is it expressed as pathological weight-bearing anteriorization? Does sATT remain elevated despite reconstruction? Is the contralateral knee similar? Are

the menisci competent? Has chronic deficiency altered the secondary stabilizers? Does the patient have constitutional hyperlaxity or recurvatum?

PTS should therefore be viewed as the beginning of assessment rather than the end of decision-making. The next era of ACL surgery should not be defined by performing an osteotomy for every knee with an angle above 12°. It should be defined by identifying which steep slopes have become mechanically expressed, which moderate slopes have become dangerous through meniscal and soft-tissue decompensation, which slopes appear to be progressing, and which anteriorized knees represent constitutional laxity that should not be treated through bone.

The goal is not simply to reconstruct the ACL or to normalize a single radiographic angle. It is to restore a sustainable biomechanical environment in which the reconstructed ligament, menisci, cartilage, and neuromuscular system can function together. The essential transition is therefore not from ACL reconstruction to slope-reducing osteotomy, but from threshold-led surgery to assessment-led personalization.

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ABBREVIATIONS

ACL: Anterior cruciate ligament

ALP: Assessment-Led Personalization

A+STRA: ACL + Slope Tracing Risk-Factor Algorithm

PTS: Posterior tibial slope

sATT: Static anterior tibial translation

REFERENCES

1. Kayaalp ME, Konstantinou E, Lucidi GA, Ak O, Mengis N, Nukuto K, et al. Advances in anterior cruciate ligament reconstruction: Risk stratification, graft choices, and functional recovery in 2026. J Exp Orthop 2026;13:e70766. [CrossRef]
2. Sevim OF, Afacan MY, Kayaalp ME. Posterior tibial slope-modifying osteotomies: Current concepts in biomechanics, indications, surgical techniques, and outcomes. Sports Traumatol Arthrosc 2026;3:36–46. [CrossRef]
3. Kayaalp ME, Winkler P, Zsidai B, Lucidi GA, Runer A, Lott A, et al. Slope osteotomies in the setting of anterior cruciate ligament deficiency. J Bone Joint Surg Am 2024;106:1615–28. [CrossRef]
4. Martin RK, Ekås GR, Benth J, Kennedy N, Moatshe G, Krych AJ, et al. Change in posterior tibial slope in skeletally immature patients with anterior cruciate ligament injury: a case series with a mean 9 years' follow-up. Am J Sports Med 2021;49:1244–50. [CrossRef]
5. Kayaalp ME, Inoue J, Nukuto K, Giusto JD, Ahrendt G, Hughes JD, et al. Posterior tibial slope increases over time in patients undergoing revision ACL reconstruction: A long-term radiographic follow-up study. Knee Surg Sports Traumatol Arthrosc 2026;34:1623–30. [CrossRef]
6. Kayaalp ME, Inoue J, Konstantinou E, Kahraman HÇ, Erden T, Musahl V. Radiographic medial posterior tibial slope ≥16° predicts multiple revisions after anterior cruciate ligament reconstruction. J Exp Orthop 2026;13:e70624. [CrossRef]
7. Kayaalp ME, Kahraman HC, Erden T, Lutter C, Scheffler S, Taser O, et al. Defining sagittal knee phenotypes via monopedal static anterior tibial translation. Part 1: Translating weight-bearing sagittal position into clinical risk profiles. Knee Surg Sports Traumatol Arthrosc 2026 Jun 24. doi:10.1002/ksa.70501. [Epub ahead of print]. [CrossRef]
8. Dejour D, Pungitore M, Valluy J, Nover L, Saffarini M, Demey G. Tibial slope and medial meniscectomy significantly influence short-term knee laxity following ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2019;27:3481–9. [CrossRef]
9. Mazy D, Cance N, Favroul C, Angelelli L, Beckers G, Dan MJ, et al. The impact of posterior tibial slope and static anterior tibial translation on ACL graft rupture rates after hamstring autograft reconstruction with lateral extra-articular tenodesis. Am J Sports Med 2025;53:2379–86. [CrossRef]
10. Mazy D, Cance N, Dan MJ, Angelelli L, Favroul C, Beckers G, et al. Selective approach to lateral extra-articular tenodesis achieves low anterior cruciate ligament graft rupture rates, while posterior tibial slope and static anterior tibial

translation remain major risk factors. Knee Surg Sports Traumatol Arthrosc. 2026 May 20. doi:10.1002/ksa.70450. [Epub ahead of print]. [CrossRef]

11. Rasmussen MT, Wilebski BJ, Tollefson LV, Carlson MR, Lee DR, Behnke RA, et al. Restoration of anterior tibial translation is achievable with an anterior cruciate ligament reconstruction and ramp repair with increasing posterior tibial slope while medial meniscus deficiency requires concomitant slope-correcting osteotomy. Am J Sports Med 2026;54:2120–9. [CrossRef]
12. Ollivier M, Mabrouk A, Parratte S, Kley K, Hirschmann MT. Beyond the posterior tibial slope: Rethinking anterior cruciate ligament (ACL) re-rupture risk through integrated scoring. Knee Surg Sports Traumatol Arthrosc 2026;34:804–14. [CrossRef]
13. Schuster P, Mayer P, Leiprecht J, Schüttler KF, Richter J, Efe T. Individualized indication for slope changing osteotomy in ACL insufficiency: the Avalanche Concept. Arch Orthop Trauma Surg 2025;146:14. [CrossRef]
14. Kayaalp ME, Kahraman HC, Erden T, Lutter C, Scheffler S, Taser O, Becker R, Hirschmann MT, Dejour DH. Defining sagittal knee phenotypes via monopedal static anterior tibial translation. Part 2: The assessment-led personalization (ALP) system for indication and correction target planning in slope-reducing osteotomy. Knee Surg Sports Traumatol Arthrosc. 2026 Jun 30. doi: 10.1002/ksa.70512. [CrossRef]
15. Vieider RP, Watrinet JM, Bilodeau R, Dadoo S, Vargas L, Mattar LT, et al. A simple planning tool for tibial slope osteotomy-Osteotomy depth is a precise parameter to determine wedge height. Knee Surg Sports Traumatol Arthrosc 2026;34:2916–25. [CrossRef]

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Original Article

Association Between Serial Weekly Suprascapular Nerve Blocks and Kinesiophobia After Arthroscopic Rotator Cuff Repair: A Retrospective Comparative Study

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ABSTRACT

Objective: Arthroscopic rotator cuff repair (ARCR) is widely used for the surgical treatment of symptomatic rotator cuff tears. Postoperative pain during the early rehabilitation period may contribute to movement-related fear, resulting in kinesiophobia and impaired functional recovery. This study aimed to evaluate whether serial weekly ultrasound-guided suprascapular nerve blocks (SSNBs), administered in conjunction with early rehabilitation sessions, were associated with reduced postoperative kinesiophobia and improved early functional outcomes after ARCR.

Materials and Methods: This retrospective comparative study evaluated prospectively collected clinical data from 87 patients aged 18 to 75 years who underwent arthroscopic repair of non-massive rotator cuff tears between January 2025 and January 2026. Group I (n=43) received four consecutive weekly ultrasound-guided SSNBs using 5 mL of 0.5% levobupivacaine via a supraclavicular approach, beginning at the sixth postoperative week and immediately before outpatient rehabilitation sessions. Group II (n=44) underwent the same standardized rehabilitation program without SSNB. The Tampa Scale for Kinesiophobia (TSK-17) was the primary outcome measure. Secondary outcomes included active range of motion (ROM) and Constant-Murley (CM) scores. Assessments were performed at the sixth postoperative week, before the initiation of active-assisted rehabilitation, and at the third postoperative month by an independent assessor blinded to group allocation.

Results: Sixth-week baseline TSK-17, CM, and ROM measurements were comparable between the groups, although Group I patients were older, and the distribution of the affected side differed significantly between the groups. At the third postoperative month, Group I had significantly lower TSK-17 scores than Group II (25.4±6.5 vs. 29.8±6.3; p<.001) and higher CM scores (88.8±3.1 vs. 84.0±3.1; p<.001). Group I also demonstrated greater forward elevation (161.3°±19.3° vs. 152.8°±16.0°; p=.007) and abduction (153.9°±23.7° vs. 145.8°±16.8°; p=.010), whereas external and internal rotation were comparable between the groups. No immediate block-related complications were observed.

Conclusion: Serial weekly SSNBs administered immediately before outpatient rehabilitation sessions after ARCR were associated with lower kinesiophobia scores, better early functional outcomes, and greater forward elevation and abduction at the third postoperative month compared with rehabilitation alone. These findings suggest that rehabilitation-synchronized SSNB may be a useful adjunct to multimodal postoperative management; however, prospective randomized studies are needed to confirm its clinical benefit.

Keywords: Kinesiophobia, physical therapy, range of motion, rotator cuff repair, suprascapular nerve block, Tampa Scale for Kinesiophobia.

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INTRODUCTION

The rotator cuff muscles are key dynamic stabilizers of the shoulder joint.[1] Rotator cuff tears (RCTs) are among the most common causes of shoulder dysfunction, and their prevalence increases with advancing age.[2,3] RCTs affect approximately 20% of the general population, with the prevalence exceeding 50% among individuals aged 70 years and older.[4,5] In patients with symptomatic supraspinatus tendon tears that fail to respond adequately to conservative treatment, surgical intervention may be indicated, and arthroscopic rotator cuff repair (ARCR) has become a standard surgical approach.[6] Early arthroscopic repair, particularly in traumatic tears, has been associated with lower retear rates and greater functional improvement than delayed repair, whereas postponing surgery beyond four months after injury may adversely affect clinical outcomes.[7] Nevertheless, successful surgical repair alone does not ensure optimal recovery, as persistent pain, joint stiffness, muscle atrophy, and the potential need for revision surgery may occur when postoperative rehabilitation is inadequate or poorly tolerated.

Kinesiophobia is characterized by an excessive and debilitating fear of movement or physical activity arising from a perceived vulnerability to pain, injury, or reinjury and may adversely affect range of motion and functional recovery.[8–10] High levels of kinesiophobia have been reported during the early postoperative period following rotator cuff repair and may interfere with rehabilitation and delay the restoration of shoulder function.[11] Postoperative pain, particularly when exercises are initiated, may contribute to the development and persistence of movement-related fear.[11,12] Accordingly, effective pain control during the early rehabilitation period may represent an important strategy for reducing kinesiophobia and facilitating participation in postoperative exercises.

Nonsteroidal anti-inflammatory drugs and opioid analgesics are commonly used for pain control following rotator cuff repair; however, their use may be associated with adverse effects, including platelet dysfunction, prolonged bleeding time, gastrointestinal complications, nausea, vomiting, sedation, and intestinal ileus. Although injection-based strategies have also been proposed for postoperative pain management, evidence regarding the efficacy of local anesthetic or corticosteroid injections remains variable.[13–15,17] Peripheral nerve blocks have therefore gained increasing attention as a targeted analgesic strategy after shoulder surgery, potentially providing effective pain relief while limiting systemic adverse effects.[16] The suprascapular nerve (SSN) provides approximately 70% of the sensory innervation of the shoulder and contributes to the innervation of the glenohumeral and acromioclavicular joints, coracoclavicular and coracohumeral ligaments, and subacromial bursa.[18,19] Owing to this extensive sensory distribution, suprascapular nerve block (SSNB) represents an effective regional analgesic option for pain management following rotator cuff repair.

Previous studies investigating kinesiophobia after rotator cuff repair have primarily considered it either as an outcome of postoperative rehabilitation or as a factor associated with postoperative pain and functional recovery. However, whether an analgesic intervention specifically synchronized with the initiation of rehabilitation can reduce early postoperative kinesiophobia remains insufficiently investigated. Therefore, the present study aimed to evaluate whether serial weekly suprascapular nerve blocks administered during the early rehabilitation period were associated with reduced postoperative kinesiophobia and improved early functional outcomes after arthroscopic rotator cuff repair. We hypothesized that patients receiving serial SSNBs would demonstrate lower postoperative kinesiophobia, greater range of motion, and better functional outcomes at the third postoperative month than patients undergoing standard rehabilitation alone.

MATERIALS AND METHODS

Patients and Study Design

This retrospective comparative study was conducted using prospectively collected clinical and follow-up data. Ethical approval for the retrospective analysis was obtained from the Bilecik Seyh Edebali University School of Medicine Ethics Committee (Decision No. 423750; Date: 30.06.2026). Informed consent had been obtained from all patients for the treatment procedures and clinical follow-up. The study was conducted in accordance with the principles of the Declaration of Helsinki.

The medical records of patients aged 18 to 75 years who were treated between January 2025 and January 2026 and underwent arthroscopic rotator cuff repair for a non-massive full-thickness supraspinatus tendon tear or a combined tear involving the supraspinatus and subscapularis tendons were retrospectively reviewed. The diagnosis had been established preoperatively based on clinical examination and imaging findings obtained by ultrasonography and/or magnetic resonance imaging (MRI).

Patients with massive rotator cuff tears, pseudoparalysis, previous surgery on the same shoulder, concomitant Bankart or SLAP lesions, a history of shoulder infection, glenohumeral osteoarthritis, a follow-up duration of less than three months, systemic rheumatic disease or malignancy, or a known allergy to the medications used for suprascapular nerve block were excluded.

Eligible patients were categorized into two groups based on the postoperative rehabilitation protocol they received. Group I consisted of patients who received serial weekly ultrasound-guided suprascapular nerve blocks (SSNBs), performed by an anesthesiologist, beginning immediately after the sixth-week postoperative assessment and before active-assisted rehabilitation sessions. Group II consisted of patients who underwent the same standardized rehabilitation program without SSNB and served as the control group.

Surgical Technique and Rehabilitation

All surgical procedures were performed by a single orthopedic surgeon with at least five years of experience in shoulder arthroscopy and rotator cuff repair. Surgery was performed under general anesthesia with the patient in the beach-chair position. Standard posterior, lateral, anterosuperior, and anteroinferior portals were used for arthroscopic evaluation of the glenohumeral joint and subacromial space. The subacromial bursa was debrided as necessary to obtain adequate visualization of the rotator cuff. Supraspinatus tendon tears were repaired using a modified Mason-Allen technique. When concomitant subscapularis tendon tears were present, they were repaired arthroscopically using a single-row technique. In patients with concomitant biceps tendon pathology, either tenotomy or tenodesis was performed according to patient age, activity level, and functional expectations.

Postoperatively, all patients were immobilized in a shoulder abduction sling at 30° for four weeks. Pendulum exercises and passive shoulder range-of-motion exercises were initiated at the fourth postoperative week, followed by active-assisted range-of-motion exercises beginning at the sixth week. Strengthening exercises were initiated at the twelfth postoperative week. The same standardized rehabilitation protocol was prescribed to both groups using written and illustrated instructions, and rehabilitation was conducted under the supervision of a physical therapist.

Suprascapular Nerve Block Technique

In Group I, the suprascapular nerve block (SSNB) was performed using a supraclavicular approach under ultrasound guidance. Patients were placed in a sitting position with the head turned toward the contralateral side. A 10–18 MHz linear ultrasound transducer was positioned in a coronal-oblique orientation over the supraclavicular region to identify the omohyoid muscle, suprascapular nerve, brachial plexus, and subclavian artery. Using an in-plane technique, an 80-mm peripheral nerve block needle was advanced toward the suprascapular nerve. Correct identification of the nerve was confirmed by eliciting supraspinatus muscle contraction with nerve stimulation, after which 5 mL of 0.5% levobupivacaine was administered. Patients were observed for 30 minutes after each procedure for potential block-related complications. SSNB was administered once weekly for four consecutive sessions, beginning with the first active-assisted outpatient physical therapy session at the sixth postoperative week. The same ultrasound-guided technique and local anesthetic regimen were used at each session. Immediately after each block, patients participated in an active-assisted exercise session under the supervision of a physical therapist.

Outcome Assessment

The Tampa Scale for Kinesiophobia (TSK-17) was used as the primary outcome measure. Secondary outcome measures included active shoulder range of motion (ROM) and the Constant-Murley (CM) score. Active forward elevation, abduction, and external rotation were measured using a goniometer, whereas internal rotation was assessed according to the highest spinal level reached by the thumb. Clinical assessments were performed at the sixth postoperative week, immediately before the initiation of the active-assisted rehabilitation program, and again at the third postoperative month. The sixth-week assessment was used as the baseline for comparing outcomes between the study groups. All assessments were performed by an independent assessor who was not involved in the treatment protocol and was blinded to group assignment.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 23.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed using the Kolmogorov-Smirnov test. Continuous variables with a normal distribution were expressed as mean±standard deviation, whereas nonnormally distributed variables were summarized using appropriate descriptive statistics. Categorical variables were presented as numbers and percentages. Between-group comparisons of continuous variables were performed using the independent-samples t test for normally distributed data and the Mann-Whitney U test for nonnormally distributed data. Categorical variables were compared using the Pearson chi-square test, Fisher's exact test, or the Fisher-Freeman-Halton test, as appropriate. Within-group comparisons between the sixth-week baseline and third-month assessments were performed using the paired-samples t test for normally distributed variables and the Wilcoxon signed-rank test for nonnormally distributed variables. For normally distributed continuous outcomes, between-group differences were additionally reported as mean differences with 95% confidence intervals. Confidence intervals were not calculated for variables analyzed using nonparametric methods or for internal rotation, which was recorded as an ordinal spinal

level. All statistical tests were two-sided, and a p value<0.05 was considered statistically significant.

RESULTS

A total of 87 patients met the eligibility criteria and were included in the analysis. Group I comprised 43 patients who received serial suprascapular nerve blocks (SSNBs) in conjunction with the postoperative rehabilitation program, whereas Group II comprised 44 patients who underwent the same rehabilitation program without SSNBs. The mean age of the overall cohort was 61.8±9.2 years, and the mean follow-up duration was 3.5±0.6 months. The study population included 47 women and 40 men. Patients in Group I were significantly older than those in Group II (64.1±7.0 vs. 59.4±10.6 years; p=.043). The mean follow-up duration was comparable between the groups (3.4±0.5 vs. 3.6±0.7 months; p=.157). A significant difference was observed in the distribution of affected sides, with right-sided involvement being more frequent in Group II (p<.001). No significant between-group differences were observed in sex distribution, history of trauma, previous physical therapy, or duration of symptoms (all p>.05). Baseline characteristics of the study groups are summarized in Table 1.

Both groups demonstrated significant improvements in Constant-Murley (CM) scores from the sixth-week postoperative baseline assessment to the third-month follow-up (p<.001 for both groups). At the sixth-week baseline assessment, CM scores were comparable between Group I and Group II (55.2±6.2 vs. 53.4±5.3, respectively; p=.213). At the third postoperative month, Group I had a significantly higher CM score than Group II (88.8±3.1 vs. 84.0±3.1; mean difference, 4.8; 95% CI, 3.5–6.1; p<.001). The comparison of CM scores between the groups is presented in Table 2.

Table 1. Baseline characteristics of the study groups

Characteristic	Group I (n=43)	Group II (n=44)	p
Age, y	64.1±7.0	59.4±10.6	**0.043**
Sex, female: male	24:19	23:21	0.831
Follow-up duration, mo.	3.4±0.5	3.6±0.7	0.157
Affected side, right: left	26:17	41:3	**<0.001**
History of trauma, yes/no	35:8	33:11	0.605
Previous physical therapy, n	26	25	0.829
Duration of symptoms, mo.	8.3±10.3	10.9±11.5	0.087

Data are presented as mean±standard deviation or number of patients, as appropriate. Bold P values indicate statistically significant between-group differences (p<0.05).

Table 2. Comparison of Constant-Murley Scores between the study groups

Assessment	Group I (n=43)	Group II (n=44)	p
Sixth-week postoperative baseline	55.2±6.2	53.4±5.3	0.213
Third postoperative month	88.8±3.1	84.0±3.1	<.001

Data are presented as mean±standard deviation. Both groups demonstrated significant within-group improvement from the sixth-week postoperative baseline to the third-month assessment (p<0.001 in both groups). The between-group mean difference and 95% confidence interval for the third-month assessment are reported in the text.

At the sixth-week postoperative baseline assessment, no significant differences in range of motion (ROM) were observed between the groups. At the third postoperative month, Group I demonstrated significantly greater abduction than Group II (153.9°±23.7° vs. 145.8°±16.8°; p=.010) and greater forward elevation (161.3°±19.3° vs. 152.8°±16.0°; p=.007). In contrast, external rotation (41.1°±8.9° vs. 41.5°±5.3°; p=.638) and internal rotation (median spinal level, L2 vs. L3; p=.100) were comparable between the groups at the third-month assessment. The between-group comparison of ROM measurements is presented in Table 3.

At the sixth-week postoperative baseline assessment, TSK-17 scores were comparable between Group I and Group II (47.8±8.7 vs. 48.4±8.4, respectively; p=.727). At the third postoperative month, Group I demonstrated a significantly lower TSK-17 score than Group II (25.4±6.5 vs. 29.8±6.3; mean difference, −4.4; 95% CI, −7.1 to −1.7; p<.001). The comparison of TSK-17 scores between the groups is presented in Table 4. No immediate block-related complications were observed during the 30-minute post-procedure monitoring period following any SSNB session.

DISCUSSION

This retrospective comparative study investigated the association of serial weekly suprascapular nerve blocks, administered at the initiation of outpatient physical therapy following arthroscopic rotator cuff repair, with postoperative kinesiophobia, range of motion, and functional outcomes. The main finding was that patients who received four consecutive weekly SSNBs before rehabilitation sessions demonstrated lower TSK-17 scores (25.4±6.5 vs. 29.8±6.3), higher Constant-Murley scores (88.8±3.1 vs. 84.0±3.1), and greater forward elevation (161.3°±19.3° vs. 152.8°±16.0°; p=.007) and abduction (153.9°±23.7° vs. 145.8°±16.8°; p=.010) at the third postoperative month compared with patients who underwent rehabilitation alone. To the best of our knowledge, this is the first study to specifically evaluate a serial weekly SSNB protocol

Table 3. Comparison of range of motion between the study groups

Range of Motion	Group I (n=43)	Group II (n=44)	p
Abduction, deg			
Sixth-week postoperative baseline	95.6±17.7	96.0±17.5	0.498
Third postoperative month	153.9±23.7	145.8±16.8	0.010
Forward elevation, deg			
Sixth-week postoperative baseline	130.5±22.3	128.8±29.5	0.826
Third postoperative month	161.3±19.3	152.8±16.0	0.007
External rotation, deg			
Sixth-week postoperative baseline	29.9±7.7	28.4±5.6	0.408
Third postoperative month	41.1±8.9	41.5±5.3	0.638
Internal rotation, spinal level			
Sixth-week postoperative baseline	Hip	Hip	0.821
Third postoperative month	L2	L3	0.100

Data are presented as mean±standard deviation for abduction, forward elevation, and external rotation, and as median spinal level for internal rotation. P values represent between-group comparisons at each assessment time point.

Table 4. Comparison of TSK-17 Scores between the study groups

Assessment	Group I (n=43)	Group II (n=44)	p
Sixth-week postoperative baseline	47.8±8.7	48.4±8.4	0.727
Third postoperative month	25.4±6.5	29.8±6.3	<0.001

Data are presented as mean±standard deviation. Both groups demonstrated a significant within-group reduction in TSK-17 scores from the sixth-week postoperative baseline to the third-month assessment. The between-group mean difference and 95% confidence interval for the third-month assessment are reported in the text.

synchronized with outpatient rehabilitation sessions after ARCR, with kinesiophobia as the primary outcome.

The rationale for using repeated rather than single-shot SSNB is based on the pharmacokinetics of local anesthetics and the recurrent pain associated with rehabilitation exercises. A single injection of 0.5% levobupivacaine provides effective analgesia for approximately 8 to 12 hours, after which its analgesic effect diminishes.[20] Because shoulder rehabilitation involves repeated exercise sessions over several weeks, a single pre-rehabilitation block provides analgesia for only a limited period. In the present protocol, weekly SSNBs were therefore administered immediately before scheduled physical therapy sessions to provide a predictable analgesic window during rehabilitation. Mortada et al. compared a single SSNB with nine repeated SSNBs in 96 patients with diabetes and frozen shoulder and reported significantly greater improvements in clinical and ultrasonographic outcomes with repeated injections.[21] Benefits of repeated or continuous suprascapular blockade combined with physical therapy have also been reported in refractory adhesive capsulitis.[22] Similar benefits have been reported in hemiplegic shoulder pain.[23] The present study extends this concept to the postoperative ARCR setting by using scheduled weekly bolus injections synchronized with rehabilitation sessions.

Both groups demonstrated significant improvements in CM scores from the sixth-week postoperative baseline to the third-month assessment (p<.001 in both groups), consistent with the established functional improvement after arthroscopic rotator cuff repair.[6,7] CM scores were comparable between the groups at the sixth-week baseline assessment (p=.213), whereas patients receiving serial SSNBs had significantly higher scores at the third postoperative month. Although the retrospective, nonrandomized design precludes attributing this difference solely to the intervention, the findings suggest a potential additional functional benefit associated with serial SSNB during rehabilitation. Coory et al. [16] demonstrated that SSNB resulted in superior CM scores compared with subacromial injection at 6 and 12 weeks in patients with symptomatic rotator cuff tears. Kim et al. [15] further reported lower VAS pain scores during the first 72 postoperative hours after ARCR with an indwelling SSNB catheter. Our findings extend this evidence by suggesting that SSNB administered specifically before rehabilitation sessions may be associated with improved functional recovery during the early postoperative period.

A key finding of the present study was the lower TSK-17 score at the third postoperative month in patients receiving serial SSNBs. Nociceptive pain during rehabilitation exercises is an important contributor to movement-related fear and avoidance behaviors.[11,12] By providing analgesia during scheduled rehabilitation sessions, repeated blocks may reduce reinforcement of the fear-avoidance cycle described in the literature.[9,10] Improved pain control during movement may facilitate participation in active-assisted exercises and reduce the negative association between shoulder movement and anticipated pain. This interpretation is consistent with

the fear-avoidance model described by Leeuw et al., in which reduced pain during exposure to movement may promote safety learning and decrease fear-related cognitions.[9] Previous studies after rotator cuff repair have also demonstrated an association between postoperative kinesiophobia and impaired functional recovery.[11] Although the present study did not directly measure pain immediately before and after each block, the lower TSK-17 scores observed in the SSNB group support further investigation into the use of analgesia during rehabilitation as a strategy to address postoperative movement-related fear.

With respect to ROM, patients receiving serial SSNBs demonstrated greater forward elevation and abduction at the third postoperative month. This finding may be related to improved tolerance of active-assisted rehabilitation during the early recovery period. Wang et al. reported that high levels of kinesiophobia during the first 6 postoperative weeks were associated with poorer ROM and functional outcomes following rotator cuff repair, suggesting that fear-related movement avoidance may contribute to limitations in early recovery.[11] Accordingly, providing analgesia during rehabilitation sessions may facilitate more effective participation in exercises, thereby contributing to early ROM gains. Similar rehabilitation-related benefits of suprascapular blockade have been reported in patients undergoing intensive treatment for adhesive capsulitis.[22] However, external and internal rotation did not differ significantly between the groups in the present study, suggesting that the observed benefit was not uniform across all planes of shoulder motion.

The supraclavicular approach used for SSNB provides reliable and repeatable localization of the suprascapular nerve in an outpatient setting without radiation exposure.[24] Ultrasound guidance facilitates direct visualization of the relevant anatomical structures and may reduce the risk of complications associated with landmark-guided techniques.[20] No immediate block-related complications were observed during the post-procedure monitoring periods across the four SSNB sessions in the present cohort, consistent with the favorable safety profile previously reported for ultrasound-guided SSNB.[14,25] Hussain et al.[25] reported a lower complication burden with suprascapular nerve block than with interscalene block, supporting its potential suitability for postoperative analgesia when avoidance of interscalene-related adverse effects is desired. In the present protocol, 0.5% levobupivacaine was used without corticosteroid, maintaining the intervention as a purely regional anesthetic technique similar to previous investigations of SSNB as an analgesic strategy after arthroscopic rotator cuff repair.[26]

Several limitations should be acknowledged. First, the retrospective, nonrandomized study design introduces the possibility of selection bias and residual confounding. Patients in Group I were significantly older than those in Group II (64.1±7.0 vs. 59.4±10.6 years; p=0.043), and the distribution of the affected side also differed significantly between the groups. These baseline imbalances may have influenced postoperative outcomes independently of the intervention. Although CM scores at the sixth-week postoperative baseline assessment were comparable between the groups (p=0.213), similarity in baseline functional status does not rule out confounding by measured or unmeasured factors. Second, the relatively short follow-up period (mean, 3.5±0.6 months) precludes conclusions regarding the long-term persistence of the observed differences in ROM, functional scores, and kinesiophobia. Wang et al.[11] reported that kinesiophobia-related functional differences may diminish over longer-term follow-up, suggesting that the advantages observed in the present study may reflect accelerated early recovery rather than sustained long-term superiority. Third, acute pain intensity was not routinely assessed using a visual analog scale immediately before and after each weekly block session. Consequently, the immediate analgesic effect of each injection and the relationship between changes in pain and kinesiophobia could not be directly quantified. Finally, although outcome assessments were performed by an independent assessor blinded to group allocation, patients and treating clinicians were aware of the treatment received. Future prospective randomized trials incorporating a sham-injection control group, standardized pain assessments at each intervention session, and longer follow-up are warranted to confirm these findings and better define the relationship between serial SSNB, pain, kinesiophobia, and functional recovery.

CONCLUSION

In conclusion, serial weekly suprascapular nerve blocks administered immediately before outpatient physical therapy sessions following arthroscopic rotator cuff repair were associated with lower kinesiophobia scores, better early functional outcomes, and greater forward elevation and abduction at the third postoperative month compared with rehabilitation alone. These findings suggest that rehabilitation-synchronized SSNB may represent a useful component of multimodal postoperative management during the early recovery period. However, given the retrospective and nonrandomized design of the present study, prospective randomized controlled trials are required to confirm the clinical benefit of this approach.

DECLARATIONS

Ethics Committee Approval: This study was approved by The Institutional Review Board at the Bilecik Şeyh Edebali University (30/06/2026 - E-10333602-050.04-423750).

Informed Consent: Written informed consent was obtained from all participants for the use of their clinical data for research purposes.

Conflict of Interest: The authors declared no conflict of interest.

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Author Contributions: Concept – MG, SY; Design – MG, SY; Supervision – SY; Data collection and/or processing – MG; Analysis and/or Interpretation – MG, SY; Literature search – MG; Writing – MG; Critical review – SY; Materials – MG, SY. All authors read and approved the final version of the manuscript.

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ABBREVIATIONS

ARCR	Arthroscopic rotator cuff repair
CI	Confidence interval
CM	Constant-Murley
MRI	Magnetic resonance imaging
RCT	Rotator cuff tear
ROM	Range of motion
SD	Standard deviation
SLAP	Superior labrum anterior to posterior
SPSS	Statistical Package for the Social Sciences
SSN	Suprascapular nerve
SSNB	Suprascapular nerve block
TSK-17	17-item Tampa Scale for Kinesiophobia
VAS	Visual analog scale

REFERENCES

1. Huegel J, Williams AA, Soslowsky LJ. Rotator cuff biology and biomechanics: a review of normal and pathological conditions. Curr Rheumatol Rep 2015;17:476. [CrossRef]
2. Dubé MO, Desmeules F, Lewis JS, Roy JS. Does the addition of motor control or strengthening exercises to education result in better outcomes for rotator cuff-related shoulder pain? A multiarm randomised controlled trial. Br J Sports Med 2023;57:457–63. [CrossRef]
3. Hinsley H, Ganderton C, Arden NK, Carr AJ. Prevalence of rotator cuff tendon tears and symptoms in a Chingford general population cohort, and the resultant impact on UK health services: a cross-sectional observational study. BMJ Open 2022;12:e059175. [CrossRef]
4. Naseri F, Dadgoo M, Pourahmadi M, Amroodi MN, Azizi S, Tabrizian P, et al. Dry needling in a multimodal rehabilitation protocol following rotator cuff repair surgery: study protocol for a double-blinded randomized sham-controlled trial. BMC Musculoskelet Disord 2023;24:330. [CrossRef]
5. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg 2010;19:116–20. [CrossRef]
6. Weber S, Chahal J. Case studies AAOS clinical practice guideline: management of rotator cuff injuries. J Am Acad Orthop Surg 2021;29:e104–8. [CrossRef]
7. Gutman MJ, Joyce CD, Patel MS, Kirsch JM, Gutman BS, Abboud JA, et al. Early repair of traumatic rotator cuff tears improves functional outcomes. J Shoulder Elbow Surg 2021;30:2475–83. [CrossRef]
8. Bordeleau M, Vincenot M, Lefevre S, Duport A, Seggio L, Breton T, et al. Treatments for kinesiophobia in people with chronic pain: A scoping review. Front Behav Neurosci 2022;16:933483. [CrossRef]
9. Leeuw M, Goossens ME, Linton SJ, Crombez G, Boersma K, Vlaeyen JW. The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. J Behav Med 2007;30:77–94. [CrossRef]
10. Turk DC, Wilson HD. Fear of pain as a prognostic factor in chronic pain: conceptual models, assessment, and treatment implications. Curr Pain Headache Rep 2010;14:88–95. [CrossRef]
11. Wang H, Hu F, Lyu X, Jia H, Wang B, Liu F, et al. Kinesiophobia could affect shoulder function after repair of rotator cuff tears. BMC Musculoskelet Disord 2022;23:714. [CrossRef]
12. Suer M, Philips N, Kliethermes S, Scerpella T, Sehgal N. Baseline kinesiophobia and pain catastrophizing scores predict prolonged postoperative shoulder pain. Pain Physician 2022;25:E285–92.
13. Kumara AB, Gogia AR, Bajaj JK, Agarwal N. Clinical evaluation of post-operative analgesia comparing suprascapular nerve block and interscalene brachial plexus block in patients undergoing shoulder arthroscopic surgery. J Clin Orthop Trauma 2016;7:34–9. [CrossRef]
14. Lee SM, Park SE, Nam YS, Han SH, Lee KJ, Kwon MJ, et al. Analgesic effectiveness of nerve block in shoulder arthroscopy: comparison between interscalene, suprascapular and axillary nerve blocks. Knee Surg Sports Traumatol Arthrosc 2012;20:2573–8. [CrossRef]
15. Kim JY, Kang MW, Lee HW, Noh KC. Suprascapular nerve block is an effective pain control method in

patients undergoing arthroscopic rotator cuff repair: a randomized controlled trial. Orthop J Sports Med 2021;9:2325967120970906. [CrossRef]

16. Coory JA, Parr AF, Wilkinson MP, Gupta A. Efficacy of suprascapular nerve block compared with subacromial injection: a randomized controlled trial in patients with rotator cuff tears. J Shoulder Elbow Surg 2019;28:430–6. [CrossRef]
17. Zadro J, Rischin A, Johnston RV, Buchbinder R. Image-guided glucocorticoid injection versus injection without image guidance for shoulder pain. Cochrane Database Syst Rev 2021;8:CD009147. [CrossRef]
18. Ritchie ED, Tong D, Chung F, Norris AM, Miniaci A, Vairavanathan SD. Suprascapular nerve block for postoperative pain relief in arthroscopic shoulder surgery: a new modality? Anesth Analg 1997;84:1306–12. [CrossRef]
19. Checcucci G, Allegra A, Bigazzi P, Gianesello L, Ceruso M, Gritti G. A new technique for regional anesthesia for arthroscopic shoulder surgery based on a suprascapular nerve block and an axillary nerve block: an evaluation of the first results. Arthroscopy 2008;24:689–96. [CrossRef]
20. Chan CW, Peng PW. Suprascapular nerve block: a narrative review. Reg Anesth Pain Med 2011;36:358–73. [CrossRef]
21. Mortada MA, Ezzeldin N, Abbas SF, Ammar HA, Salama NA. Multiple versus single ultrasound guided suprascapular nerve block in treatment of frozen shoulder in diabetic patients. J Back Musculoskelet Rehabil 2017;30:537–42. [CrossRef]
22. Martens G, Fontaine R, Goffin P, Raaf M, Tasset H, Lecoq JP, et al. Continuous suprascapular nerve blockade to potentiate intensive rehabilitation for refractory adhesive shoulder capsulitis: a cohort study. Int Orthop 2024;48:495–503. [CrossRef]
23. Dogan AT, Pekin Dogan Y, Aytekin E, Sogut S, Gokkaya Z, Tumer M, et al. Effectiveness of repeated ultrasound-guided suprascapular nerve blocks in hemiplegic shoulder pain: A randomized controlled trial. Medicine (Baltimore) 2026;105:e47547. [CrossRef]
24. Siegenthaler A, Moriggl B, Mlekusch S, Schliessbach J, Haug M, Curatolo M, et al. Ultrasound-guided suprascapular nerve block, description of a novel supraclavicular approach. Reg Anesth Pain Med 2012;37:325–8. [CrossRef]
25. Hussain N, Goldar G, Ragina N, Banfield L, Laffey JG, Abdallah FW. Suprascapular and interscalene nerve block for shoulder surgery: a systematic review and meta-analysis. Anesthesiology 2017;127:998–1013. [CrossRef]
26. Desroches A, Klouche S, Schlur C, Bauer T, Waitzenegger T, Hardy P. Suprascapular nerve block versus interscalene block as analgesia after arthroscopic rotator cuff repair: a randomized controlled noninferiority trial. Arthroscopy 2016;32:2203–9. [CrossRef]

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Original Article

Arthroscopic Pull-Out Suture Fixation versus Double-Loop Cortical Button Fixation for ACL Tibial Eminence Avulsion Fractures: A Retrospective Comparative Study

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ABSTRACT

Objective: This study aimed to compare the perioperative, radiological, and clinical outcomes of arthroscopic pull-out suture fixation and double-loop cortical button fixation for anterior cruciate ligament (ACL) tibial eminence avulsion fractures.

Materials and Methods: This retrospective, two-center comparative study included patients who underwent arthroscopic fixation for ACL tibial eminence avulsion fractures between August 2022 and November 2024. Patients with modified Meyers and McKeever type IIIA or IIIB fractures and a minimum follow-up of 12 months were included. Patients were divided into two groups according to fixation technique: pull-out suture fixation and double-loop cortical button fixation. Demographic and perioperative variables, radiological union, Lysholm Knee Score, range-of-motion deficits, Lachman test results, and revision surgery were evaluated. Patients who underwent revision surgery were retained in the revision analysis, but post-revision clinical findings were excluded from the final comparison of clinical outcomes.

Results: A total of 37 patients were included: 19 in the pull-out suture fixation group and 18 in the double-loop cortical button fixation group. There were no significant differences between the groups in baseline characteristics, fracture type, time from injury to surgery, operation time, length of hospital stay, or follow-up duration. Radiological union was observed in all patients except the patient who underwent revision surgery, and no nonunion or secondary displacement was detected among patients who completed follow-up without revision. Final clinical outcomes were compared between 19 patients in the pull-out suture fixation group and 17 patients in the double-loop cortical button fixation group. The Lysholm Knee Score did not differ significantly between the groups (84.7±8.6 vs. 87.1±8.9, p=0.231). Extension deficit, flexion deficit, and Lachman grade distribution were also similar between the groups. One patient in the double-loop cortical button fixation group required revision ACL reconstruction, whereas no patient in the pull-out suture fixation group required revision (p=0.486).

Conclusion: No statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, and clinical outcomes evaluated in this cohort. Given the small sample size, these findings should not be interpreted as demonstrating equivalence between the two techniques. Double-loop cortical button fixation may represent an alternative fixation option for selected type IIIA and IIIB fractures.

Keywords: ACL avulsion fracture, arthroscopy, cortical button fixation, Endobutton, pull-out suture fixation, tibial eminence fracture, tibial spine fracture.

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INTRODUCTION

Tibial eminence avulsion fractures are intra-articular injuries in which the anterior cruciate ligament (ACL) is avulsed from its tibial insertion with an attached bony fragment.[1,2] Although these injuries are classically regarded as the pediatric equivalent of midsubstance ACL rupture, they may also occur in skeletally mature patients, particularly after sports trauma or high-energy mechanisms.[1–3] Because displaced fragments may alter ACL tension and knee kinematics, inadequate reduction or fixation may result in residual anterior instability, restricted range of motion, nonunion, or secondary degenerative changes.[2,4]

The Meyers and McKeever classification, with later modifications by Zaricznyj, remains the most widely used system for describing these fractures.[5,6] While nondisplaced type I fractures are generally treated nonoperatively, displaced type III fractures and comminuted type IV fractures usually require surgical reduction and fixation.[1,2,6]The management of type II fractures remains more controversial, particularly when residual displacement or soft-tissue interposition prevents anatomic reduction.[2] In recent years, arthroscopic treatment has become the preferred approach because it allows direct visualization of the fracture bed, assessment and treatment of concomitant intra-articular lesions, less soft-tissue morbidity, and accurate reduction.[1,4,7]

Several arthroscopic fixation methods have been described, including screw fixation, Kirschner wires, suture anchors, pull-out sutures, suture bridge constructs, and cortical button-based techniques.[1,4,8–12] Pull-out suture fixation is one of the most commonly used arthroscopic techniques and is particularly useful for small or comminuted fragments where screw fixation may not be feasible.[2,8,11] However, concerns remain regarding fixation strength, suture cut-through, fragment control, and the ability to allow early rehabilitation.[9–11] Double-loop cortical button fixation has been proposed as an alternative method that may provide stable fixation with a broader implant–bone interface and may reduce the risk of fragment fragmentation or fixation failure.[4,9,10] Nevertheless, the available evidence for this technique remains limited, and comparative clinical data against conventional pull-out suture fixation are scarce.[4,8,9]

The aim of the present study was to compare the perioperative, radiological, and clinical outcomes of arthroscopic pull-out suture fixation and double-loop cortical button fixation in patients with ACL tibial eminence avulsion fractures. We hypothesized that double-loop cortical button fixation would provide clinical outcomes comparable to or better than pull-out suture fixation without increasing operative time, postoperative motion limitation, residual laxity, or the revision surgery rate.

MATERIALS AND METHODS

Study Design and Patient Selection

This retrospective, two-center comparative study was conducted at the Department of Orthopedics and Traumatology, Selçuk University Faculty of Medicine, Konya, Türkiye, and the Department of Orthopedics and Traumatology, University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye. Patients who underwent arthroscopic fixation for anterior cruciate ligament tibial eminence avulsion fractures between August 2022 and November 2024 were evaluated. The study protocol was approved by the institutional ethics committee, and informed consent was obtained from all patients (Ethics Committee Approval No.: 3/7; Approval Date: 05 February 2026). Patients were divided into two groups according to the fixation technique used: arthroscopic pull-out suture fixation and arthroscopic double-loop cortical button fixation. Because this was a retrospective study, treatment allocation was not randomized, and no predefined allocation protocol was used. The choice between pull-out suture fixation and double-loop cortical button fixation was made according to the preference of the operating surgeon. Both fixation techniques were used across the two participating centers.

Patients with ACL tibial eminence avulsion fractures who were treated arthroscopically with either of these two fixation techniques and had a minimum follow-up duration of 12 months were included in the study. The inclusion criteria were Meyers and McKeever type IIIA or IIIB tibial eminence avulsion fractures, complete perioperative records, and available final clinical and radiological follow-up data. Patients were excluded if they had associated tibial plateau fractures or other periarticular fractures requiring additional fixation, multiligament knee injuries requiring ligament reconstruction at the index surgery, previous surgery on the affected knee, chronic neglected fractures or nonunion, open fractures, neurovascular injuries, incomplete medical records, or a follow-up duration shorter than 12 months. Demographic and perioperative data, including age, sex, affected side, body mass index, fracture type, time from injury to surgery, operation time, length of hospital stay, and follow-up duration, were collected from hospital records. Clinical and radiological outcomes were assessed at the final follow-up.

Preoperative Assessment

All patients were evaluated clinically and radiologically before surgery. Standard anteroposterior and lateral knee radiographs were obtained in all cases. Computed tomography was used to define fracture morphology, displacement, rotation, and comminution (Fig. 1). Magnetic resonance imaging was obtained when needed to evaluate ACL continuity and

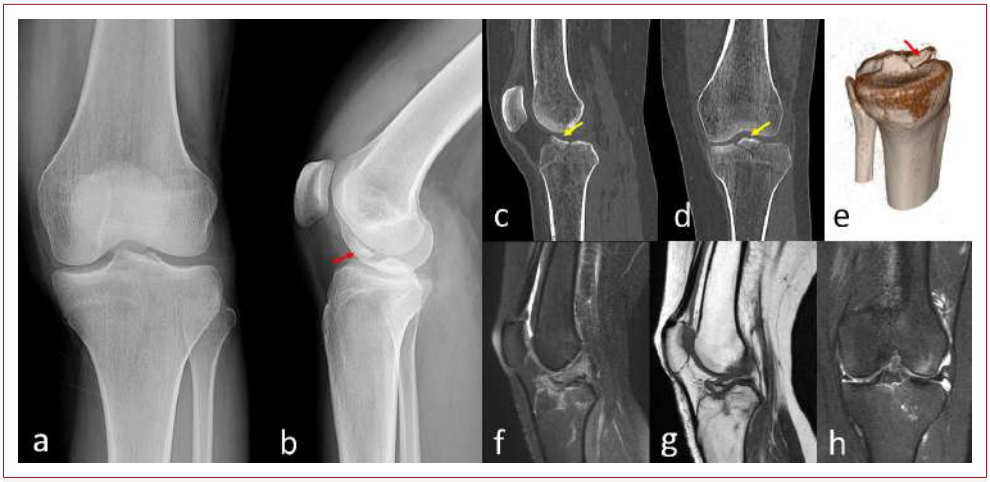

Figure 1. Preoperative radiological evaluation of a 20-year-old female patient with tibial eminence avulsion fracture. Anteroposterior **(a)** and lateral **(b)** knee radiographs show an avulsion fracture of the tibial eminence; the red arrow on the lateral radiograph indicates the displaced avulsed fragment. Sagittal **(c)** and coronal **(d)** computed tomography images demonstrate the fracture morphology, displacement, and involvement of the intercondylar eminence; yellow arrows indicate the displaced fragment of the tibial eminence. Three-dimensional reconstruction **(e)** further illustrates the displaced avulsed fragment, marked by the red arrow. Sagittal and coronal magnetic resonance images **(f–h)** demonstrate the relationship of the avulsed fragment with the anterior cruciate ligament and allow assessment of associated intra-articular injuries.

possible associated meniscal, chondral, or ligamentous injuries. Fractures were classified according to the modified Meyers and McKeever classification (Fig. 2).[5,6] In our treatment algorithm, type I and type II fractures were managed conservatively when acceptable reduction and knee stability could be achieved. Type IV fractures, which are characterized by comminution of the avulsed fragment, were not included because double-loop cortical button fixation was considered unsuitable for these fracture patterns; instead, pull-out suture fixation was preferred for comminuted fragments to allow secure capture of multiple small fragments and the ACL substance. Therefore, to provide a more homogeneous comparison between the two fixation techniques, only type IIIA and type IIIB fractures with a single large displaced fragment were included in the present study. Surgical treatment was indicated for completely displaced or rotated fragments requiring anatomic reduction and stable fixation to restore ACL tension and knee stability.

Surgical Technique

All procedures were performed under spinal or general anesthesia with the patient in the supine position. A pneumatic tourniquet was applied over the thigh. Standard anterolateral and anteromedial arthroscopic portals were used. After evacuation of the hemarthrosis, diagnostic arthroscopy was performed to evaluate the ACL, fracture fragment, menisci, cartilage, and other intra-articular structures. Interposed hematoma, fibrous tissue, and soft-tissue structures preventing reduction were removed. The fracture bed was carefully debrided, and the avulsed fragment was anatomically reduced under direct arthroscopic visualization.

In the pull-out suture fixation group, the avulsed fragment and the ACL substance near its tibial insertion were secured using high-strength sutures. Sutures were passed through the ACL base and/or around the bony fragment using an arthroscopic suture passer, similar to previously described pull-out suture techniques.[3,13–15] A single tibial tunnel was created from the anteromedial proximal tibial cortex toward the fracture bed using an ACL tibial guide. The suture limbs were retrieved through the tibial tunnel and tensioned under arthroscopic visualization to achieve anatomic reduction of the fragment.[3,13–15] After arthroscopic confirmation of anatomic reduction and appropriate ACL tension, the suture limbs were tensioned through the tibial tunnel and fixed over the distal anterior tibial cortex using a cortical screw and washer as a post-fixation construct. The washer was used to distribute the compressive force and prevent suture slippage during tying. The sutures were securely tied around the screw–washer construct while maintaining reduction under arthroscopic visualization. The knee was then cycled through flexion and extension, and

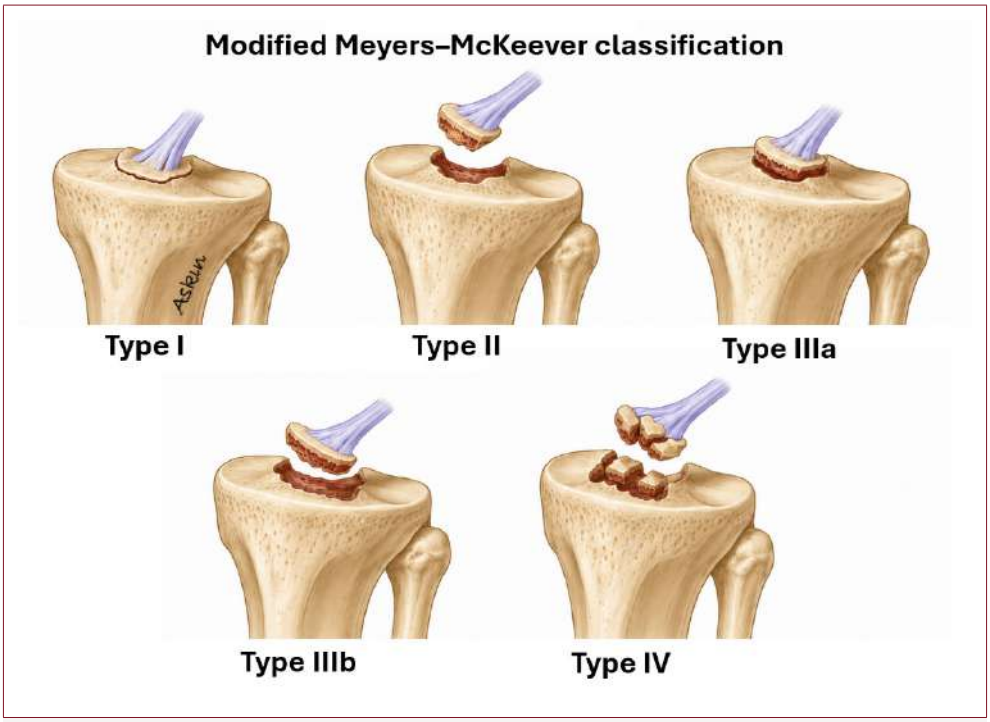

Figure 2. Modified Meyers–McKeever classification of tibial eminence fractures[5, 6]. Schematic illustration showing the fracture patterns of anterior cruciate ligament tibial eminence avulsion fractures. Type I represents a nondisplaced fracture. Type II represents a partially displaced fracture with posterior hinging. Type IIIA represents complete displacement of the avulsed fragment involving the ACL insertion. Type IIIB represents complete displacement involving the entire intercondylar eminence. Type IV represents a comminuted displaced fracture fragment.

the stability of the fixation, ACL tension, and maintenance of fracture reduction were confirmed arthroscopically and fluoroscopically.[13–15]

In the double-loop cortical button fixation group, the fracture fragment was reduced arthroscopically after preparation of the fracture bed, as previously described for Endobutton- and cortical button-based fixation techniques.[4,8,9] A tibial tunnel was created from the anteromedial proximal tibial cortex toward the tibial eminence using an ACL tibial guide. A double-loop cortical button construct was then passed through the tibial tunnel and positioned over the avulsed fragment under direct arthroscopic visualization. The loop was tensioned to compress the fragment against the fracture bed and restore ACL tension.[4,9] The distal loop was secured on the anteromedial tibial cortex using a cortical button fixation system. Reduction, compression of the avulsed fragment, and fixation stability were checked arthroscopically. The knee was cycled several times through the range of motion to confirm that reduction was maintained and that there was no impingement or loss of fixation. Final reduction was confirmed by fluoroscopy.[4,8,9] The fixation principles of the two arthroscopic techniques are illustrated schematically in Figure 3, demonstrating pull-out suture fixation with distal tibial cortical screw–washer fixation and double-loop cortical button fixation with cortical button stabilization.

Postoperative Rehabilitation

The same postoperative rehabilitation protocol was used for both groups. After surgery, the knee was immobilized in a hinged knee brace locked in extension, consistent with previously described postoperative protocols for arthroscopic fixation of tibial eminence fractures.[3,4] Isometric quadriceps exercises, ankle pump exercises, and straight-leg raises were started in the early postoperative period as tolerated.[3] Partial weight-bearing with crutches was allowed during the first two weeks, as tolerated, with adjustments based on pain, swelling, and fixation stability. Passive and active-assisted range-of-motion exercises were gradually initiated after 2 weeks, with progressive flexion according to the rehabilitation protocol.[4] Full weight-bearing was allowed once radiological signs of healing were present

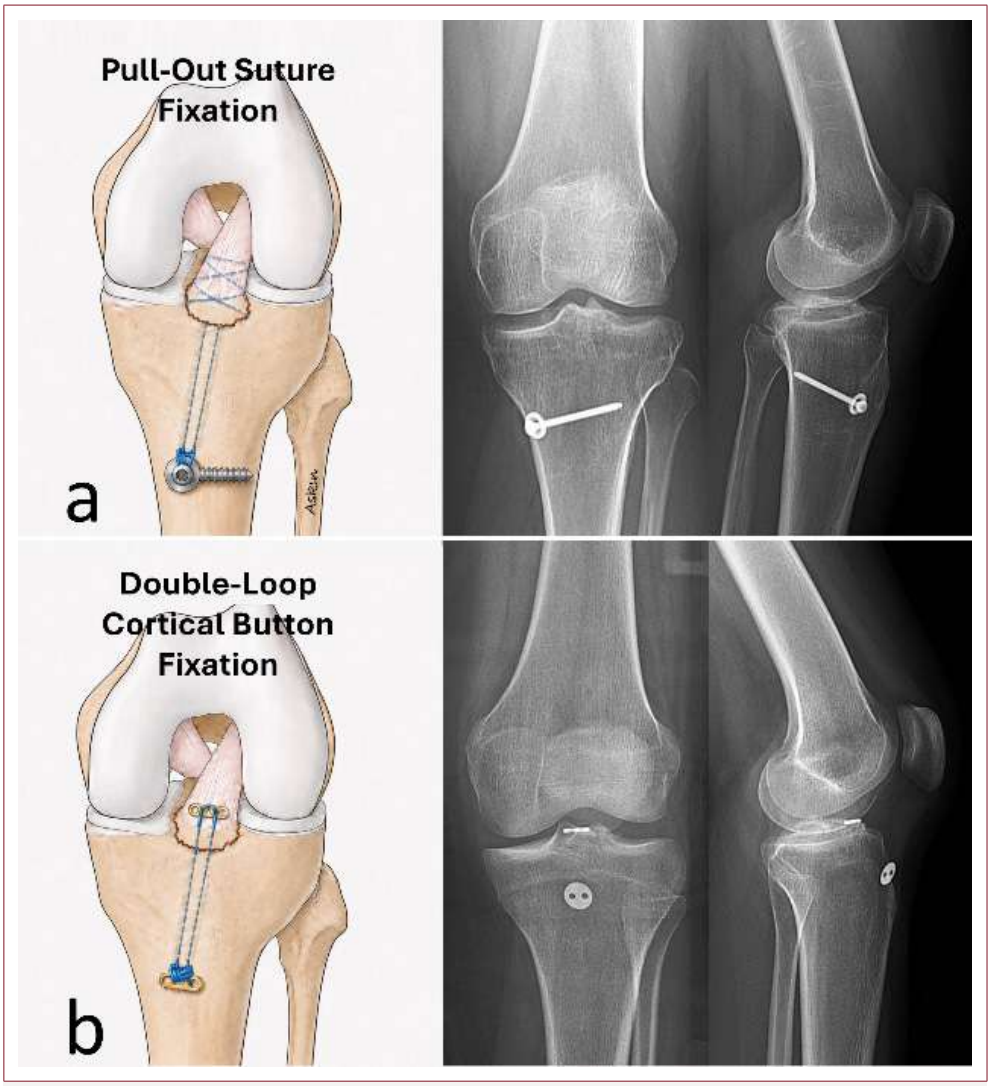

Figure 3. Schematic illustrations and representative postoperative radiographs of the two arthroscopic fixation techniques for ACL tibial eminence avulsion fractures. **(a)** Arthroscopic pull-out suture fixation. High-strength sutures are passed through the ACL substance and around the avulsed tibial eminence fragment, then retrieved through the tibial tunnel and fixed over the distal anterior tibial cortex with a cortical screw and washer construct. **(b)** Arthroscopic double-loop cortical button fixation. The avulsed fragment is reduced arthroscopically and compressed using a double-loop cortical button construct, with proximal cortical button fixation over the fragment and distal cortical button fixation on the anterior tibial cortex.

and adequate quadriceps control was achieved.[3] Running and sport-specific activities were permitted after clinical and radiological union, restoration of range of motion, absence of instability, and sufficient muscle strength.[16] The rehabilitation protocol was adjusted as needed based on fracture stability, concomitant intra-articular lesions, pain, swelling, and range-of-motion recovery.

Follow-up and Outcome Assessment

Patients were followed clinically and radiologically according to each institution's routine postoperative follow-up protocol. Because of the retrospective nature of the study, follow-up intervals were not identical for all patients. Available postoperative radiographs and clinical records were reviewed to assess fracture union, maintenance of reduction, range of

motion (ROM), knee stability, complications, and the need for revision surgery. Range of motion was measured in degrees relative to the contralateral knee. For the categorical analysis, any measurable loss of extension or flexion (>0°) was recorded as a ROM deficit. Because this definition also captures minor motion loss, clinically relevant ROM loss was additionally defined as an extension deficit of ≥5° or a flexion deficit of ≥10°. All eligible patients were invited for a final follow-up examination, during which clinical outcomes were assessed using the Lysholm Knee Score, ROM measurements, and the Lachman test. At each participating center, the Lachman test was performed at the final follow-up by the designated orthopedic surgeon responsible for clinical follow-up at that center; thus, two assessors were involved overall, with one assessor at each center. The test was performed using the same clinical examination approach at both centers, and laxity was recorded according to the predefined grading system.

Radiological union was evaluated using the available postoperative and final follow-up radiographs. Radiological union was assessed on anteroposterior and lateral knee radiographs and was defined as disappearance or substantial blurring of the fracture line, with restoration of trabecular continuity across the fracture site and maintenance of fracture reduction without secondary displacement. Radiological assessments were performed by a single experienced orthopedic surgeon who reviewed the available postoperative and final follow-up radiographs. One patient who underwent revision surgery with subsequent ACL reconstruction was retained in the baseline, perioperative, and revision surgery analyses. However, post-revision clinical examination findings were excluded from the final clinical outcome comparison because these values could be influenced by the secondary ACL reconstruction rather than the index fixation technique. Revision surgery was analyzed separately as a treatment-failure endpoint.

Statistical Analysis

No formal a priori sample size calculation or power analysis was performed because of the retrospective study design; all eligible patients who met the inclusion criteria during the predefined study period were included. Statistical analysis was performed to compare baseline characteristics, perioperative variables, and clinical outcomes between the pull-out suture fixation and double-loop cortical button fixation groups. Continuous variables were reported as mean±standard deviation and median [interquartile range], whereas categorical variables were reported as number and percentage. Because of the relatively small sample size, continuous variables were compared between the groups using the Mann–Whitney U test. Categorical variables were compared using Fisher's exact test. The final clinical outcome analysis included only patients who did not undergo revision surgery. One patient in the double-loop cortical button fixation group underwent revision surgery with subsequent anterior cruciate ligament reconstruction; therefore, post-revision clinical examination findings were excluded from the final clinical outcome analysis to avoid confounding by the secondary procedure. However, this patient was retained in the baseline, perioperative, and revision surgery analyses. Revision surgery was analyzed separately as a treatment-failure endpoint. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significant.

RESULTS

A total of 37 patients who met the inclusion criteria were included in the study. Nineteen patients underwent arthroscopic pull-out suture fixation, and 18 patients underwent arthroscopic double-loop cortical button fixation. At the first center, 4 patients underwent pull-out suture fixation and 11 underwent double-loop cortical button fixation, whereas at the second center, 15 patients underwent pull-out suture fixation and 7 underwent double-loop cortical button fixation. The distribution of fixation techniques differed between the two centers (Fisher's exact test, p=0.020). The baseline demographic and perioperative characteristics of the two groups are summarized in Table 1. There were no statistically significant differences between the groups in terms of age, sex distribution, affected side, body mass index, fracture type, time from injury to surgery, operation time, length of hospital stay, or follow-up duration. The mean age was 28.1±12.4 years in the pull-out suture fixation group and 25.7±8.4 years in the double-loop cortical button fixation group. The median time from injury to surgery was 4.0 days in both groups. Operation time was comparable between the groups, with a mean of 69.6±7.0 minutes in the pull-out suture fixation group and 67.9±7.8 minutes in the double-loop cortical button fixation group. The median follow-up duration was 26.0 months in the pull-out suture fixation group and 24.0 months in the double-loop cortical button fixation group.

Radiological union was evaluated using available postoperative and final follow-up radiographs. Radiological union of the tibial eminence fracture was observed in all patients except the patient who underwent revision surgery. No nonunion or secondary displacement was detected among patients who completed follow-up without revision surgery. Final clinical outcomes are summarized in Table 2. One patient in the double-loop cortical button fixation group underwent revision surgery with ACL reconstruction due to persistent anterior knee laxity after the index fixation; therefore, post-revision clinical examination findings were excluded from the

Table 1. Baseline and perioperative characteristics of the patients

Variable	Data Units	Pull-out Suture Fixation (n=19)	Double-Loop Cortical Button Fixation (n=18)	p
Age	years±SD	28.1±12.4	25.7±8.4	0.915
	median [IQR]	23.0 [17.0–37.5]	23.5 [19.0–32.5]	
Sex	Male, n (%)	14 (73.7)	17 (94.4)	0.180
	Female, n (%)	5 (26.3)	1 (5.6)	
Side	Right, n (%)	8 (42.1)	8 (44.4)	1.000
	Left, n (%)	11 (57.9)	10 (55.6)	
BMI	kg/m^2±SD	26.7±5.4	25.6±5.1	0.503
	median [IQR]	26.0 [23.0–30.0]	25.5 [22.0–28.0]	
Fracture Type	Type IIIa, n (%)	12 (63.2)	12 (66.7)	1.000
	Type IIIb, n (%)	7 (36.8)	6 (33.3)	
Center	Center 1	4 (21.1)	11 (61.1)	0.020
	Center 2	15 (78.9)	7 (38.9)	
Time to surgery	days±SD	4.9±1.9	4.3±2.3	0.294
	median [IQR]	4.0 [3.5–6.0]	4.0 [3.0–5.8]	
Operation time	min.±SD	69.6±7.0	67.9±7.8	0.538
	median [IQR]	70.0 [65.0–75.0]	67.5 [64.2–73.0]	
LOS	days±SD	2.8±1.0	2.7±0.8	0.895
	median [IQR]	2.0 [2.0–3.0]	3.0 [2.0–3.0]	
Follow-up	months±SD	25.6±5.0	26.1±5.6	0.903
	median [IQR]	26.0 [22.0–28.0]	24.0 [22.2–29.8]	

Data are presented as mean±standard deviation and median [interquartile range] for continuous variables, and as number (%) for categorical variables. Continuous variables were compared between groups using the Mann–Whitney U test. Categorical variables were compared using Fisher's exact test. BMI: body mass index; IQR: interquartile range; LOS: length of hospital stay; SD: standard deviation.

final clinical outcome comparison. This patient was retained in the analysis of revision surgery. Accordingly, final clinical outcomes were compared between 19 patients in the pull-out suture fixation group and 17 patients in the double-loop cortical button fixation group.

The Lysholm Knee Score was comparable between the groups. The mean Lysholm score was 84.7±8.6 in the pull-out suture fixation group and 87.1±8.9 in the double-loop cortical button fixation group, with no statistically significant difference. Extension and flexion deficits were also similar between the groups. The mean extension deficit was 0.8±3.4° in the pull-out suture fixation group and 0.6±2.4° in the double-loop cortical button fixation group. The mean flexion deficit was 6.3±5.0° and 6.8±6.1°, respectively.

Lachman test findings were similar between the groups. Grade 0 Lachman was observed in 14 patients in the pull-out suture fixation group and 13 patients in the double-loop cortical button fixation group. Grade 1 Lachman was observed in 5 and 4 patients, respectively. No patient had grade 2 Lachman laxity in the final clinical outcome analysis.

Revision surgery was required in one patient in the double-loop cortical button fixation group and in none of the patients in the pull-out suture fixation group. The revision surgery rate did not differ statistically between the groups. Overall, no statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, or clinical outcomes evaluated in this cohort.

DISCUSSION

The most important finding of the present study was that arthroscopic pull-out suture fixation and double-loop cortical button fixation provided comparable perioperative, radiological, and clinical outcomes in patients with type IIIa and IIIb ACL tibial eminence avulsion fractures. No significant differences were observed between the two techniques in terms of operation time, length of hospital stay, follow-up

Table 2. Clinical outcomes according to fixation technique

Variable	Data Units	Pull-out Suture Fixation (n=19)	Double-Loop Cortical Button Fixation (n=17*)	p
Lysholm Knee Score	score±SD	84.7±8.6	87.1±8.9	0.231
	median [IQR]	80.0 [80.0–90.0]	90.0 [80.0–95.0]	
Extension deficit	°±SD	0.8±3.4	0.6±2.4	1.000
	median [IQR]	0.0 [0.0–0.0]	0.0 [0.0–0.0]	
Flexion deficit	°±SD	6.3±5.0	6.8±6.1	0.961
	median [IQR]	5.0 [2.5–10.0]	5.0 [0.0–10.0]	
Flexion deficit ≥10°	n, (%)	8/19 (42.1)	7/17 (41.2)	1.000
Extension deficit ≥5°	n, (%)	1/19 (5.3)	1/17 (5.9)	1.000
Lachman	Grade 0, n (%)	14 (73.7)	13 (76.5)	1.000
	Grade 1, n (%)	5 (26.3)	4 (23.5)	
	Grade 2, n (%)	0 (0.0)	0 (0.0)	
Revision surgery	n (%)	0/19 (0.0)	1/18 (5.6)	0.486

Data are presented as mean±standard deviation and median [interquartile range] for continuous variables, and as number (%) for categorical variables. Continuous variables were compared between groups using the Mann–Whitney U test. Binary categorical variables were compared using Fisher's exact test. *One patient in the double-loop cortical button fixation group underwent revision surgery with ACL reconstruction; therefore, post-revision clinical examination findings were excluded from the final clinical outcome analysis, whereas the patient was retained in the revision surgery analysis. IQR: interquartile range; SD: standard deviation.

duration, Lysholm Knee Score, range-of-motion deficits, Lachman grade distribution, or revision surgery rate. Radiological union was achieved in all patients who completed follow-up without revision surgery, and no nonunion or secondary displacement was detected. Although one patient in the double-loop cortical button fixation group required revision ACL reconstruction, the overall revision rate did not differ significantly between the groups. These findings suggest that double-loop cortical button fixation may be a safe and effective alternative to conventional pull-out suture fixation in selected displaced tibial eminence avulsion fractures with a single large fragment.

Tibial eminence avulsion fractures are relatively uncommon injuries, and the optimal fixation method remains debated because several arthroscopic techniques have been described without a clearly established gold standard.[1,17,18] Recent literature has emphasized that arthroscopic fixation is the predominant surgical approach for displaced fractures, as it allows anatomic reduction, assessment of associated intra-articular lesions, and stable fixation with less soft-tissue morbidity.[1,4,17,18] In the present study, radiological union was achieved in all patients who completed follow-up without revision surgery, and no secondary displacement or nonunion was observed. These findings are consistent with previous reports showing high union rates and satisfactory clinical outcomes after arthroscopic fixation of displaced tibial eminence avulsion fractures.[3,4,8,16,19,20]

Pull-out suture fixation is one of the most commonly used arthroscopic techniques for tibial eminence avulsion fractures, particularly when the fragment is small or when screw fixation may increase the risk of fragmentation.[2,9,13] Previous studies have reported favorable functional outcomes, restoration of knee stability, and high union rates after arthroscopic pull-out suture fixation.[3,16,19,20] Kocher et al. [16] reported excellent long-term functional outcomes after arthroscopic-assisted pull-out suture fixation, with high Lysholm scores, restored anterior knee stability, and return to sport without significant impairment. Similarly, other clinical series have described the pull-out suture technique as a straightforward and reliable method for fixation of ACL tibial avulsion fractures.[3,20] In the present study, the pull-out suture fixation group also demonstrated satisfactory functional outcomes, with a mean Lysholm score of 84.7 and no revision surgery.

Cortical button-based fixation has been introduced as an alternative technique to improve fixation stability and fragment control.[4,8–10,21] The proposed advantages of Endobutton or cortical button constructs include compression over a broader implant–bone interface, reduced risk of suture cut-through, and avoidance of intra-articular screw-related problems.[8–10,21] Yıldırım et al. [4] reported successful short-term outcomes in 13 patients treated with a double-loop Endobutton device, with radiological union in all patients and negative Lachman and pivot-shift tests at the final follow-up. Sekiya et al. [8] also described secure fixation with an Endobutton technique, reporting bone union, stable knees,

excellent range of motion, and negative Lachman and pivot-shift tests in all five patients. In the present study, the double-loop cortical button fixation group showed Lysholm scores, range-of-motion outcomes, and Lachman grade distribution comparable to those of the pull-out suture group, supporting the use of this method as an alternative fixation strategy for selected type IIIa and IIIb fractures.

An important point in interpreting the present study is fracture selection. Type IV comminuted fractures were excluded because these fractures are less suitable for double-loop cortical button fixation and are more commonly managed with suture-based techniques that can capture multiple small fragments and the ACL substance.[2,6,9] By including only type IIIa and IIIb fractures with a single large displaced fragment, the present study attempted to create a more homogeneous cohort and a more balanced comparison between the two fixation methods. This design may help reduce bias that could arise if comminuted fractures were disproportionately treated with pull-out sutures.

The revision case in the double-loop cortical button group should be interpreted cautiously. Although this patient required subsequent ACL reconstruction, the overall revision rate did not differ statistically between the groups. In addition, post-revision clinical findings were excluded from the final clinical outcome analysis to avoid confounding by the secondary ACL reconstruction. This approach allowed the revision event to be analyzed as a treatment-failure endpoint while preventing post-reconstruction knee function from being incorrectly attributed to the index fixation technique.

The present study has several strengths. First, it directly compared two arthroscopic fixation techniques for ACL tibial eminence avulsion fractures, whereas most previous studies have reported outcomes of a single technique without a control group. Second, only modified Meyers and McKeever type IIIa and IIIb fractures were included, creating a more homogeneous cohort with a single large displaced fragment and allowing a more balanced comparison between pull-out suture fixation and double-loop cortical button fixation. Third, the study was conducted at two centers and included clinically relevant perioperative, radiological, and functional outcomes, such as operative time, radiological union, Lysholm Knee Score, range of motion, Lachman test findings, and the need for revision surgery.

This study also has limitations. The retrospective design carries an inherent risk of selection bias, and the fixation technique was not randomized but was selected according to the operating surgeon's preference. Moreover, the distribution of the two fixation techniques differed between the participating centers, raising the possibility of center- and surgeon-related confounding. Therefore, differences in institutional practice and surgeon-related factors may have influenced the observed outcomes and should be considered when interpreting the comparisons between the two techniques. The sample size was relatively small, and no a priori sample size calculation or formal equivalence or non-inferiority analysis was performed. Therefore, the study may have been underpowered to detect clinically relevant between-group differences, particularly for uncommon outcomes such as revision surgery, nonunion, or secondary displacement. Accordingly, the absence of statistically significant differences should not be interpreted as evidence of equivalence between the two fixation techniques. Follow-up intervals and radiographic assessments were not fully standardized because of the retrospective nature of the study. Radiological union was assessed using available postoperative and final follow-up radiographs rather than a uniform computed tomography protocol. In addition, objective instrumented measurements of laxity, such as KT-1000 or Rolimeter testing, were not available. Patient-reported outcomes other than the Lysholm Knee Score, as well as detailed return-to-sport data, were not evaluated. Finally, because type IV comminuted fractures were excluded, the findings cannot be generalized to all patterns of tibial eminence avulsion fractures.

CONCLUSION

In conclusion, no statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, and clinical outcomes evaluated in patients with modified Meyers and McKeever type IIIa and IIIb ACL tibial eminence avulsion fractures. Radiological union was achieved in all patients who completed follow-up without revision surgery, and no secondary displacement or nonunion was observed. However, because of the small sample size and the absence of an equivalence or non-inferiority analysis, these findings should not be interpreted as demonstrating equivalence between the two techniques. Double-loop cortical button fixation may be an alternative for selected fracture patterns, but larger prospective studies are needed to establish its comparative effectiveness and safety.

DECLARATIONS

Ethics Committee Approval: This study was approved by the Ethics committee of Antalya Training and Research Hospital (Approval No.: 3/7, Date: 05.02.2026).

Informed Consent: Written informed consent was obtained from all patients who participated in the study.

Conflict of Interest: The authors declared no conflict of interest.

Financial Disclosure: The authors declared that they have no relevant or material financial interests that relate to the research described in this paper.

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Peer-review: Externally peer-reviewed.

ABBREVIATIONS

ACL: Anterior cruciate ligament

BMI: Body mass index

CT: Computed tomography

IQR: Interquartile range

LOS: Length of hospital stay

MRI: Magnetic resonance imaging

ROM: Range of motion

SD: Standard deviation

REFERENCES

1. Landré V, Teuben M, Klingebiel FK, Shehu A, Ensle F, Pape HC, et al. Tibial anterior cruciate ligament avulsion fractures in pediatric and adult populations: a systematic literature review. J Clin Med 2025;14:6316. [CrossRef]
2. Leeberg V, Lekdorf J, Wong C, Sonne-Holm S. Tibial eminentia avulsion fracture in children - a systematic review of the current literature. Dan Med J 2014;61:A4792.
3. Kumar Das T, Dash M, Dash A, Mishra J, Zion N. Evaluation of the suture pull-out technique in anterior cruciate ligament avulsion fractures at different weeks post-fracture. Cureus 2024;16:e69126. [CrossRef]
4. Yıldırım A, Aydın BK, Çiftci S, Güleç A. Arthroscopic treatment of tibial eminence fractures using double-loop endobutton device: Surgical technique and short-term treatment outcomes. Jt Dis Relat Surg 2020;31:456–62. [CrossRef]
5. Meyers MH, Mckeever FM. Fracture of the intercondylar eminence of the tibia. J Bone Joint Surg Am 1959;41-A:209–20; discussion 220–2. [CrossRef]
6. Zaricznyj B. Avulsion fracture of the tibial eminence: treatment by open reduction and pinning. J Bone Joint Surg Am 1977;59:1111–4. [CrossRef]
7. McLennan JG. The role of arthroscopic surgery in the treatment of fractures of the intercondylar eminence of the tibia. J Bone Joint Surg Br 1982;64:477–80. [CrossRef]
8. Sekiya H, Takatoku K, Kimura A, Kanaya Y, Fukushima T, Takeshita K. Arthroscopic fixation with EndoButton for tibial eminence fractures visualised through a proximal superomedial portal: a surgical technique. J Orthop Surg (Hong Kong) 2016;24:417–20. [CrossRef]
9. Pape D, Giffin R. Arthroscopic endobutton fixation for tibial eminence fractures: surgical technique. J Knee Surg 2005;18:203–5. [CrossRef]
10. Hapa O, Barber FA, Süner G, Özden R, Davul S, Bozdağ E, et al. Biomechanical comparison of tibial eminence fracture fixation with high-strength suture, EndoButton, and suture anchor. Arthroscopy 2012;28:681–7. [CrossRef]
11. Bong MR, Romero A, Kubiak E, Iesaka K, Heywood CS, Kummer F, et al. Suture versus screw fixation of displaced tibial eminence fractures: a biomechanical comparison. Arthroscopy. 2005;21:1172–6. [CrossRef]
12. Sawyer GA, Hulstyn MJ, Anderson BC, Schiller J. Arthroscopic suture bridge fixation of tibial intercondylar eminence fractures. Arthrosc Tech 2013;2:e315–8. [CrossRef]
13. Hunter RE, Willis JA. Arthroscopic fixation of avulsion fractures of the tibial eminence: technique and outcome. Arthroscopy 2004;20:113–21. [CrossRef]
14. Kogan MG, Marks P, Amendola A. Technique for arthroscopic suture fixation of displaced tibial intercondylar eminence fractures. Arthroscopy 1997;13:301–6. [CrossRef]
15. Matthews DE, Geissler WB. Arthroscopic suture fixation of displaced tibial eminence fractures. Arthroscopy 1994;10:418–23. [CrossRef]
16. Kocher FM, Galofaro L, Schwab JM, Raabe I, Tannast M, Petek D. Tibial eminence avulsion fracture in pediatric patients reinserted with arthroscopy and pull-out suture technique: clinical and functional outcomes in a long-term follow up with return to sport. Children (Basel) 2025;12:499. [CrossRef]
17. Osti L, Buda M, Soldati F, Del Buono A, Osti R, Maffulli N. Arthroscopic treatment of tibial eminence fracture: a systematic review of different fixation methods. Br Med Bull 2016;118:73–90. [CrossRef]
18. Gans I, Baldwin KD, Ganley TJ. Treatment and management outcomes of tibial eminence fractures in pediatric patients: a systematic review. Am J Sports Med 2014;42:1743–50. [CrossRef]

19. Pan RY, Yang JJ, Chang JH, Shen HC, Lin LC, Lian YT. Clinical outcome of arthroscopic fixation of anterior tibial eminence avulsion fractures in skeletally mature patients: a comparison of suture and screw fixation technique. J Trauma Acute Care Surg 2012;72:E88–93. [CrossRef]
20. Ahn JH, Yoo JC. Clinical outcome of arthroscopic reduction and suture for displaced acute and chronic tibial spine fractures. Knee Surg Sports Traumatol Arthrosc 2005;13:116–21. [CrossRef]
21. Kelly S, DeFroda S, Nuelle CW. Arthroscopic assisted anterior cruciate ligament tibial spine avulsion reduction and cortical button fixation. Arthrosc Tech 2023;12:e1033–8. [CrossRef]

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Original Article

Varus Alignment, Increased Lateral Posterior Tibial Slope, and Decreased PCL Footprint Angle Are Independently Associated with Isolated Degenerative Medial Meniscus Posterior Root Tears: A Matched Case-Control Study

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ABSTRACT

Objective: The purpose of this study was to investigate the relationship between isolated degenerative medial meniscus posterior root tears (MMPRTs) and varus alignment, lateral and medial posterior tibial slopes (LPTS and MPTS), and the PCL tibial footprint angle (PCL-FPA).

Materials and Methods: This retrospective matched case-control study included 192 patients aged 40–65 years without ACL pathology. Ninety-six patients with MMPRT were matched 1:1 by age and sex with 96 controls, yielding 96 matched pairs. LPTS and MPTS were measured on sagittal MRI using the Hudek technique; PCL-FPA was defined as the angle between the tibial longitudinal axis and the PCL footprint line on MRI; and varus alignment was assessed by measuring the mechanical axis angle on full-length weight-bearing radiographs. Mann-Whitney U and chi-square tests were used for between-group comparisons, and Firth-penalized logistic regression analysis was used to identify independently associated parameters.

Results: Compared with the control group, the MMPRT group demonstrated significantly higher LPTS (10.94±3.25° vs. 7.51±3.03°; p<0.001) and varus alignment (4.38±1.77° vs. 2.59±1.51°; p<0.001), and significantly lower PCL-FPA (49.95±7.55° vs. 54.62±6.27°; p<0.001). MPTS was similar between the groups (p=0.479). On multivariable analysis, LPTS (OR=1.497; 95% CI 1.283–1.746; p<0.001), varus alignment (OR=2.199; 95% CI 1.656–2.922; p<0.001), and PCL-FPA (OR=0.935; 95% CI 0.881–0.992; p=0.026) were independently associated with isolated degenerative MMPRT. ROC analysis revealed the highest individual AUC for varus alignment (AUC=0.790; 95% CI 0.724–0.851), while the combined model yielded an AUC of 0.885 (95% CI 0.835–0.929).

Conclusion: Isolated degenerative MMPRT is independently associated with varus alignment, increased LPTS, and decreased PCL-FPA. MPTS was not significantly associated with MMPRT in this ACL-intact cohort. Increased LPTS may reflect altered rotational knee biomechanics related to MMPRT, whereas decreased PCL-FPA may represent a distinct posterior tibial attachment geometry related to the medial meniscus posterior root. Further biomechanical studies and external validation are needed to confirm these findings.

Keywords: Magnetic resonance imaging, Meniscus, Meniscus injuries, Risk factors, Tibial slope, Varus deformity.

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INTRODUCTION

Medial meniscus posterior root tears (MMPRTs) account for approximately 10–21% of meniscal tears and remain an important, potentially underdiagnosed cause of knee dysfunction.[1] Medial meniscus posterior root tears constitute approximately 52% of all meniscal root tears, occur more commonly in women, and typically present in middle age.[1] Current concepts regarding the anatomy, diagnosis, and treatment of meniscal root tears continue to evolve.[2] Disruption of posterior root integrity compromises the ability of the meniscus to convert axial loads into circumferential hoop stresses, resulting in a marked increase in tibiofemoral contact pressure and producing biomechanical changes comparable to those observed after total meniscectomy.[3,4] The resulting loss of functional meniscal support has been associated with accelerated progression of knee osteoarthritis, even in patients without pre-existing radiographic osteoarthritis.[5]

Osseous morphology has increasingly been recognized as an important factor associated with MMPRT. Systematic reviews have identified increased medial posterior tibial slope, varus alignment, and reduced intercondylar dimensions as morphometric features associated with MMPRT.[6,7] However, most previous investigations have focused primarily on tibial slope and coronal alignment, whereas the potential contribution of posterior tibial attachment geometry remains poorly understood. In particular, the relationship between the tibial attachment geometry of the posterior cruciate ligament (PCL) and MMPRT has not previously been investigated. The tibial attachment of the PCL is located approximately 1.0–1.5 cm distal to the joint line, and the center of the medial meniscus posterior root lies only 8.2±0.7 mm from the nearest border of the PCL tibial attachment.[8] This close anatomical relationship raises the possibility that the PCL tibial footprint angle (PCL-FPA) may provide indirect information regarding posterior tibial attachment morphology adjacent to the medial meniscus posterior root. Although attachment-site orientation has been shown to influence enthesis biomechanics in other anatomical structures,[9,10] whether such geometric characteristics are associated with MMPRT remains unknown.

The purpose of this study was to investigate the associations of varus alignment, lateral posterior tibial slope (LPTS), medial posterior tibial slope (MPTS), and PCL-FPA with isolated degenerative MMPRT in an ACL-intact population compared with an age- and sex-matched control group.

MATERIALS AND METHODS

Study Design and Patient Selection

This study was designed as a retrospective matched case-control study. Following institutional review board approval (approval date: 27 February 2026; no. 236), the institutional archive was searched to identify patients who underwent knee MRI between January 2018 and December 2023. The MMPRT group consisted of patients diagnosed with isolated medial meniscus posterior root tears confirmed by arthroscopy or MRI. Of the 96 patients with MMPRT, 56 had arthroscopic confirmation, whereas 40 were diagnosed by MRI alone based on established imaging criteria for posterior root tears, including radial/cleft, ghost, and truncation signs. The control group consisted of individuals who underwent MRI for nonspecific anterior knee pain and had no meniscal root pathology. These patients were selected as controls because they underwent knee MRI using comparable protocols, enabling standardized measurements, while lacking meniscal root pathology.

For the purposes of this study, degenerative MMPRT was defined as a posterior root tear occurring without a history of significant acute knee trauma in patients aged 40–65 years, with MRI findings and, where available, arthroscopic findings consistent with a degenerative rather than an acute traumatic tear. The inclusion criteria were: (1) a diagnosis of isolated MMPRT, (2) availability of adequate-quality sagittal MRI images, and (3) age between 40 and 65 years. The exclusion criteria were: (1) concomitant ACL tear or a history of ACL reconstruction, (2) lateral meniscus root tear, (3) advanced knee osteoarthritis (Kellgren–Lawrence grade 3–4), (4) previous knee surgery, and (5) inflammatory joint disease. A total of 96 patients with MMPRT met these criteria and were included in the study.

Matching Strategy

Age- and sex-matched pairing was performed to ensure demographic comparability between the groups. The institutional database was searched to identify eligible control candidates who met the inclusion criteria. When multiple control candidates of the same age and sex were available for a given MMPRT patient, selection was performed by random sampling. Control selection was performed independently of radiological measurement results. This process yielded 96 matched pairs (192 patients in total).

Imaging Protocol and Radiological Measurements

All patients underwent a standardized knee MRI protocol. Images were obtained in the sagittal, coronal, and axial planes using proton density-weighted fat-suppressed sequences. Varus alignment was assessed by measuring the mechanical axis angle on full-length weight-bearing radiographs. Full-length weight-bearing radiographs were available for all patients and were obtained within a comparable time interval relative to the index MRI using the same standardized acquisition protocol. MRI evaluations and radiographic

measurements were performed with the investigators blinded to clinical and group information.

Posterior Tibial Slope Measurement: MPTS and LPTS were measured on sagittal MRI sections using the method described by Hudek et al.[11] The tibial longitudinal axis was determined using the two-circle method, and the posterior tibial slope was measured as the angle between the tangent to the tibial plateau and the line perpendicular to this axis. MPTS and LPTS were measured separately on the medial and lateral tibial plateau sections, respectively (Fig. 1).

PCL Footprint Angle (PCL-FPA): The PCL-FPA was a novel radiological measurement parameter defined in this study. It was measured on the sagittal MRI section in which the PCL tibial attachment was most clearly visualized as the angle between the tibial longitudinal axis and a line drawn parallel to the PCL tibial footprint surface. The tibial longitudinal axis was determined using the two-circle method described by Hudek et al., and the PCL footprint line was drawn parallel to the attachment surface of the PCL fibers on the tibia (Fig. 2).

Varus Alignment: Varus alignment was assessed by measuring the mechanical axis varus angle on full-length weight-bearing radiographs. This angle was defined as the angle between the line extending from the center of the femoral head to the center of the knee joint and the line extending from the center of the knee joint to the midpoint of the superior articular surface of the talus. Positive values indicated varus alignment, whereas negative values indicated valgus alignment (Fig. 3).

Reliability Analysis

All measurements were performed independently by two orthopedic surgeons in two separate sessions. Intra- and interobserver agreement was assessed using the intraclass correlation coefficient (ICC); ICC values ranged from 0.82 to 0.93 (Table 1).

Statistical Analysis

Continuous variables were expressed as mean±standard deviation (SD), and categorical variables as frequencies and percentages. The normality of continuous variables was assessed using the Shapiro–Wilk test. Between-group comparisons were performed using the independent-samples t-test for normally distributed continuous variables and the Mann–Whitney U test for non-normally distributed continuous variables. Categorical variables were compared using the chi-square test or Fisher's

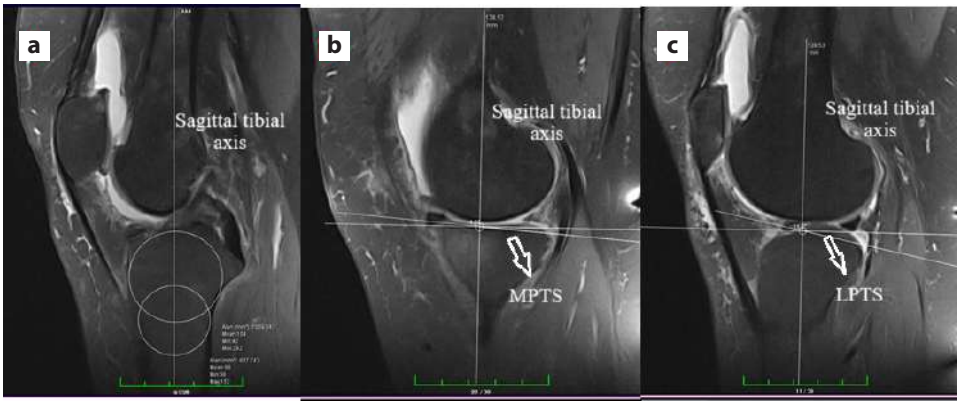

Figure 1. Measurement of posterior tibial slope on sagittal MRI. **(a)** The sagittal tibial longitudinal axis is established by drawing two circles tangent to the anterior and posterior tibial cortices on the sagittal MRI section in which the PCL tibial attachment, the intercondylar eminence, and the anterior and posterior tibial cortices are visible. The center of the caudal circle is placed at the border of the cranial circle, and the line connecting the two centers defines the tibial longitudinal axis. **(b)** Medial posterior tibial slope (MPTS) is measured as the angle between the tangent to the medial tibial plateau articular surface (arrow) and the perpendicular to the tibial longitudinal axis on the medial sagittal MRI section. **(c)** Lateral posterior tibial slope (LPTS) is measured using the same method on the lateral sagittal MRI section (arrow). Representative case: 59-year-old female with isolated degenerative MMPRT. MPTS: 4.3°, LPTS: 11.3°. *(MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; MRI: magnetic resonance imaging.)*

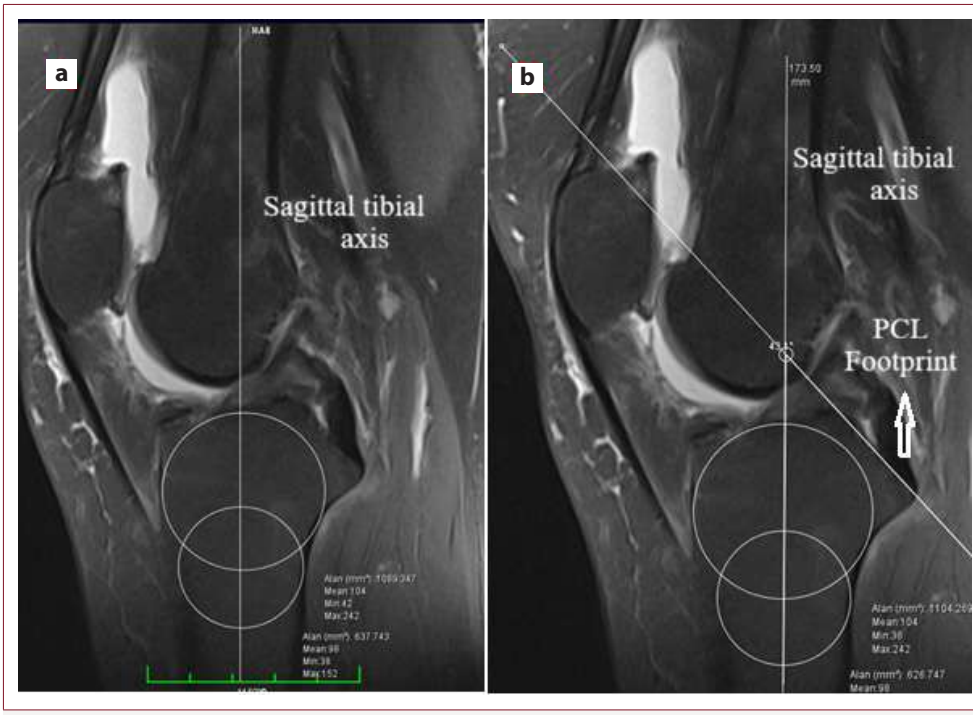

Figure 2. Measurement of the PCL tibial footprint angle (PCL-FPA) on sagittal MRI. **(a)** The sagittal tibial longitudinal axis is determined using the two-circle method on the sagittal MRI section where the PCL tibial attachment is best visualized. **(b)** A line is drawn parallel to the PCL tibial footprint (i.e., along the attachment surface of the PCL fibers on the tibia); PCL-FPA is then measured as the angle between this footprint line and the sagittal tibial longitudinal axis (arrow). Representative case: 59-year-old female with isolated degenerative MMPRT. PCL-FPA: 43.1°. *(PCL-FPA: PCL footprint angle; PCL: posterior cruciate ligament; MRI: magnetic resonance imaging.)*

exact test, as appropriate. Associations between radiological parameters and isolated degenerative MMPRT were evaluated using Firth-penalized logistic regression analysis. Each morphometric parameter was first assessed in a univariable model. Variables with a p-value<0.05 in the univariable analysis were subsequently entered into the multivariable Firth-penalized logistic regression model. Firth penalization was used to reduce small-sample bias and the potential effect of sparse data on maximum-likelihood estimates. Age and sex were balanced through the matching procedure and were therefore not included as covariates. Collinearity among the morphometric variables was assessed using pairwise correlations, and no evidence of problematic multicollinearity was identified. Regression results were reported as odds ratios (ORs) with 95% confidence intervals (CIs). Model performance was additionally summarized using McFadden's R^2 and the Akaike information criterion (AIC). The discriminative performance of the radiological parameters was assessed using receiver operating characteristic (ROC) curve analysis. Areas under the curve (AUCs) with 95% CIs were calculated, and optimal cutoff values were determined using the Youden index, with corresponding sensitivity and specificity values. The ROC curve for the combined model was generated from the predicted probabilities of the multivariable Firth-penalized logistic regression model. A two-sided p-value<0.05 was considered statistically significant. Statistical analyses were performed using R version 4.3.0 and SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Demographic Characteristics

A total of 192 patients were included, comprising 96 patients with isolated degenerative MMPRT and 96 age- and sex-matched controls. The mean age was 51.2±5.3 years in both groups, and 77 patients (80.2%) in each group were female. The distribution of the side of the evaluated knee was also similar between the groups (p=0.878) (Table 2).

Radiological Measurements

MPTS was similar between the MMPRT and control groups (9.56±2.76° vs. 9.22±2.73°, respectively; p=0.479). In contrast,

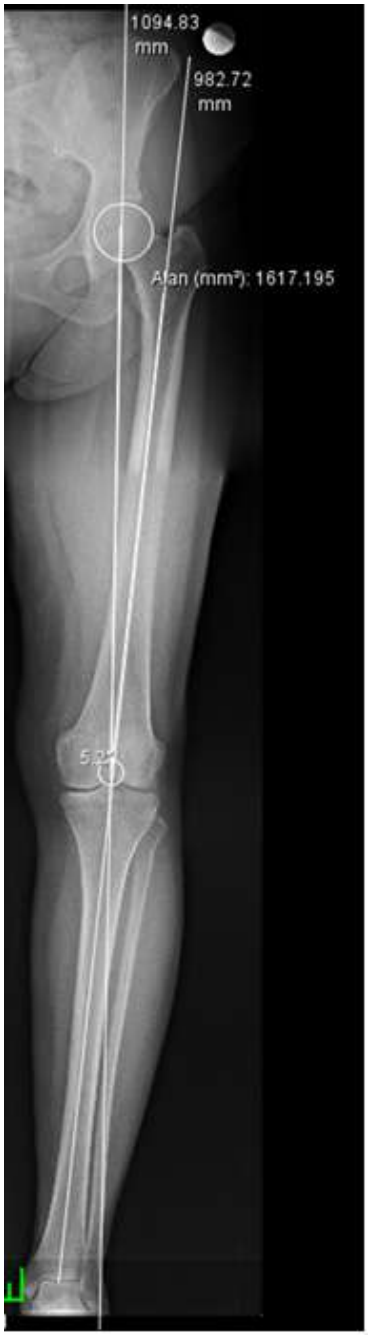

Figure 3. Measurement of varus alignment on a full-length weight-bearing radiograph. The mechanical axis varus angle is measured as the angle between two lines: the line drawn from the center of the femoral head to the center of the knee joint, and the line drawn from the center of the knee joint to the midpoint of the superior articular surface of the talus. Positive values indicate varus, and negative values indicate valgus alignment. Representative case: 59-year-old female with isolated degenerative MMPRT. Varus alignment: 5.2°.

Table 1. Intra- and inter-rater reliability of radiological measurements in the MMPRT and control groups

Radiological Parameter	Reliability Measure	MMPRT Group ICC	Control Group ICC
MPTS	Intra-rater, Observer 1	0.88	0.89
	Intra-rater, Observer 2	0.86	0.84
	Inter-rater	0.83	0.83
LPTS	Intra-rater, Observer 1	0.93	0.91
	Intra-rater, Observer 2	0.90	0.88
	Inter-rater	0.90	0.86
Varus alignment	Intra-rater, Observer 1	0.83	0.82
	Intra-rater, Observer 2	0.85	0.89
	Inter-rater	0.85	0.86
PCL-FPA	Intra-rater, Observer 1	0.92	0.93
	Intra-rater, Observer 2	0.88	0.85
	Inter-rater	0.87	0.87

MMPRT: medial meniscus posterior root tear; ICC: intraclass correlation coefficient.

LPTS was significantly greater in the MMPRT group than in the control group (10.94±3.25° vs. 7.51±3.03°; p<0.001). Varus alignment was also significantly greater in the MMPRT group (4.38±1.77° vs. 2.59±1.51°; p<0.001). PCL-FPA was significantly lower in the MMPRT group than in the control group (49.95±7.55° vs. 54.62±6.27°; p<0.001) (Table 3).

Firth-Penalized Logistic Regression Analysis

In the univariable Firth-penalized logistic regression analysis, MPTS was not significantly associated with isolated degenerative

Table 2. Demographic characteristics of the study groups

Parameter	Control (n=96)	Isolated MMPRT (n=96)	p
Age (years), mean±SD	51.2±5.3	51.2±5.3	1.000
Female, n (%)	77 (80.2)	77 (80.2)	1.000
Right knee, n (%)	47 (49.0)	46 (47.9)	0.878

SD: standard deviation; MMPRT: medial meniscus posterior root tear.

Table 3. Comparison of radiological measurements between the study groups

Parameter	Control (n=96)	Isolated MMPRT (n=96)	p
MPTS (°), mean±SD	9.22±2.73	9.56±2.76	0.479
LPTS (°), mean±SD	7.51±3.03	10.94±3.25	<0.001
Varus alignment (°), mean±SD	2.59±1.51	4.38±1.77	<0.001
PCL-FPA (°), mean±SD	54.62±6.27	49.95±7.55	<0.001

MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle; SD: standard deviation.

Table 4. Univariable Firth-penalized logistic regression analysis

Variable	OR	95% CI	p
MPTS	1.047	0.944–1.162	0.384
LPTS	1.419	1.263–1.595	<0.001
Varus alignment	2.076	1.618–2.663	<0.001
PCL-FPA	0.907	0.867–0.949	<0.001

OR: odds ratio; CI: confidence interval; MPTS: medial posterior tibial slope; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle.

Table 5. Multivariable Firth-penalized logistic regression analysis

Variable	OR	95% CI	p
LPTS	1.497	1.283–1.746	<0.001
Varus alignment	2.199	1.656–2.922	<0.001
PCL-FPA	0.935	0.881–0.992	0.026

OR: odds ratio; CI: confidence interval; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle. McFadden R^2=0.395; AIC=169.0.

MMPRT (OR=1.047; 95% CI, 0.944–1.162; p=0.384). In contrast, greater LPTS (OR=1.419; 95% CI, 1.263–1.595; p<0.001), greater varus alignment (OR=2.076; 95% CI, 1.618–2.663; p<0.001), and lower PCL-FPA (OR=0.907; 95% CI, 0.867–0.949; p<0.001) were significantly associated with MMPRT (Table 4).

In the multivariable Firth-penalized logistic regression model, greater LPTS (OR=1.497; 95% CI, 1.283–1.746; p<0.001), greater varus alignment (OR=2.199; 95% CI, 1.656–2.922; p<0.001), and lower PCL-FPA (OR=0.935; 95% CI, 0.881–0.992; p=0.026) remained independently associated with isolated degenerative MMPRT. The model yielded a McFadden R^2 of 0.395 and an AIC of 169.0 (Table 5). Accordingly, each 1° increase in LPTS and varus alignment was associated with higher odds of MMPRT, whereas each 1° increase in PCL-FPA was associated with lower odds of MMPRT.

ROC Curve Analysis and Optimal Cutoff Values

Among the individual radiological parameters, varus alignment demonstrated the highest discriminative ability for isolated degenerative MMPRT, with an AUC of 0.790 (95% CI, 0.724–0.851). The optimal cutoff value for varus alignment was ≥3.2°, yielding a sensitivity of 71.9% and a specificity of 74.0%. LPTS demonstrated an AUC of 0.763 (95% CI, 0.693–0.824). The optimal cutoff value was ≥11.3°, with a sensitivity of 46.9% and a specificity of 91.7%. PCL-FPA demonstrated an AUC of 0.675 (95% CI, 0.598–0.745), with an optimal cutoff value of ≤50.1°, yielding a sensitivity of 53.1% and a specificity of 75.0%. MPTS demonstrated limited discriminative ability, with an AUC of 0.530 (95% CI, 0.502–0.612). The combined model incorporating varus alignment, LPTS, and PCL-FPA demonstrated greater discriminative performance than any individual parameter, with an AUC of 0.885 (95% CI, 0.835–0.929), a sensitivity of 75.0%, and a specificity of 86.5% (Table 6, Fig. 4).

DISCUSSION

In this matched case-control study, varus alignment, increased LPTS, and decreased PCL-FPA were independently associated with isolated degenerative MMPRT. Notably, PCL-FPA, a newly introduced morphometric parameter, demonstrated an independent association with MMPRT, suggesting that posterior tibial attachment geometry may represent an additional anatomical factor related to this condition. In contrast to previous reports emphasizing the role of MPTS, MPTS was not significantly associated with MMPRT in the present cohort, whereas LPTS remained independently associated in the multivariable model. These findings indicate that the morphometric profile of isolated degenerative MMPRT in an ACL-intact population may differ from that described in more heterogeneous cohorts. By excluding concomitant ACL pathology and using age- and sex-matched controls, the present study provides a more focused assessment of the relationship between tibial morphology and degenerative MMPRT.

The relationship between PTS and MMPRT is among the most frequently studied morphometric associations in the literature. Increased PTS has been biomechanically shown to increase compressive and anteriorly directed shear forces on the MMPR.[12] Systematic reviews have demonstrated associations between MMPRT and increased medial tibial slope, varus alignment, and reduced intercondylar dimensions.[6,7] In contrast, MPTS was similar between the groups in our study

Table 6. ROC analysis and optimal cutoff values for radiological parameters

Parameter	AUC	95% CI	Optimal cutoff	Sensitivity (%)	Specificity (%)
Varus alignment	0.790	0.724-0.851	≥3.2°	71.9	74.0
LPTS	0.763	0.693–0.824	≥11.3°	46.9	91.7
PCL-FPA	0.675	0.598–0.745	≤50.1°	53.1	75.0
Combined model	0.885	0.835–0.929	—	75.0	86.5

AUC: area under the receiver operating characteristic curve; CI: confidence interval; LPTS: lateral posterior tibial slope; PCL-FPA: posterior cruciate ligament footprint angle. Optimal cutoff values were determined using the Youden index.

and was not significantly associated with MMPRT (p=0.479). This finding may be related to differences in patient selection. A considerable proportion of the existing literature includes MMPRT cases with concomitant ACL pathology or uses patients with other meniscal tears as controls.[6] Differences in ACL status, control-group selection, and associated knee pathology may therefore contribute to the variability in reported associations between MPTS and MMPRT.

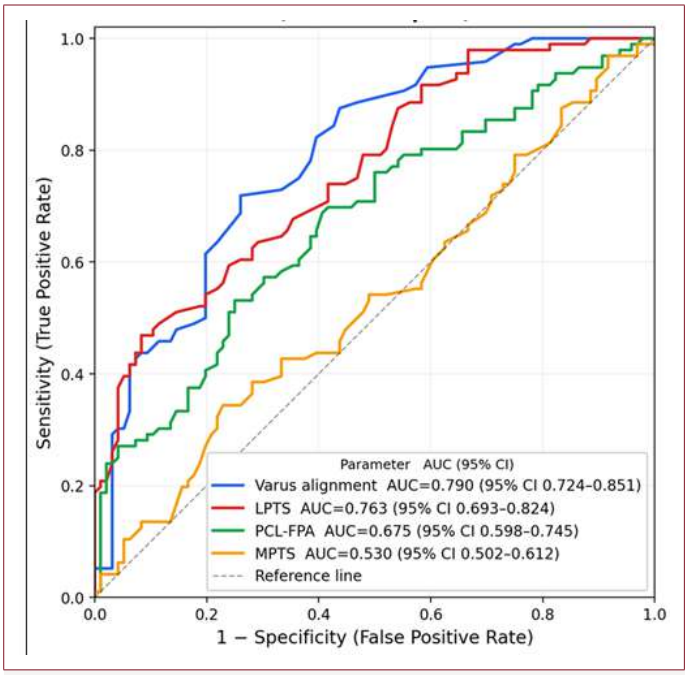

Figure 4. ROC curves for radiological parameters associated with isolated degenerative MMPRT (96 matched pairs). Varus alignment showed the highest individual AUC (0.790; 95% CI, 0.724–0.851), followed by LPTS (AUC=0.763; 95% CI, 0.693–0.824) and PCL-FPA (AUC=0.675; 95% CI, 0.598–0.745). MPTS demonstrated limited discriminative performance (AUC=0.530; 95% CI, 0.502–0.612). AUC: area under the curve; CI: confidence interval; LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope; MMPRT: medial meniscus posterior root tear; PCL-FPA: posterior cruciate ligament footprint angle; ROC: receiver operating characteristic.

One notable finding of our study was that LPTS remained independently associated with MMPRT in the multivariable analysis (OR=1.497; p<0.001). The relationship between LPTS and MMPRT has not been systematically investigated in the literature. However, existing biomechanical evidence may provide a potential explanation for this association. Increased LPTS has been associated with greater anterior translation of the lateral tibial compartment and changes in tibial rotational kinematics.[7] Moreover, asymmetry between LPTS and MPTS has been reported to correlate with dynamic anterior tibial translation and may influence tibial displacement during loading.[13] These findings provide a possible biomechanical basis for the association observed between increased LPTS and MMPRT. A relatively steeper lateral slope may promote greater anterior translation of the lateral compartment and alter tibial rotational mechanics, potentially increasing loading of the medial compartment and posterior meniscus root. Confirmation of this association in larger cohorts and biomechanical studies is warranted. The recognized role of tibial slope in knee biomechanics has also prompted increasing interest in posterior tibial slope-modifying osteotomies, further emphasizing the potential clinical relevance of slope-related parameters.[14]

Varus alignment demonstrated the highest individual discriminative ability in our study (AUC=0.790) and remained independently associated with MMPRT in the multivariable analysis (OR=2.199; p<0.001). This finding is consistent with the existing literature. In a large series of 476 patients, the mean varus mechanical axis angle was significantly greater in patients with MMPRT than in controls (4.5°±3.4° vs. 2.4°±2.7°; p<0.01), closely corresponding to the values observed in our study (4.38° vs. 2.59°).[15] Varus alignment has also been consistently identified as a morphometric factor associated with MMPRT in systematic reviews.[7] The persistence of this association in an ACL-intact population further supports the

importance of coronal alignment and medial compartment loading in degenerative MMPRT.

PCL-FPA is a novel radiological measurement parameter defined in this study and was independently associated with MMPRT in the multivariable analysis (OR=0.935; p=0.026). The weak correlations between PCL-FPA and MPTS and LPTS suggest that PCL-FPA may capture anatomical information that is largely distinct from tibial slope measurements. A potential anatomical basis for this association is the close proximity between the PCL tibial attachment and the medial meniscus posterior root. Cadaveric studies have demonstrated that the center of the medial meniscus posterior root lies only 8.2±0.7 mm from the nearest border of the PCL tibial attachment.[8] Given this close anatomical relationship, PCL-FPA may reflect not only the sagittal orientation of the PCL tibial attachment but also aspects of posterior tibial attachment geometry adjacent to the medial meniscus posterior root. Furthermore, given the role of the PCL in posterior tibial restraint and rotational stability, variation in PCL-FPA may also be related to biomechanical characteristics relevant to loading of the medial meniscus posterior root.[10]

From a biomechanical perspective, a decreased PCL-FPA represents a more horizontally oriented PCL tibial footprint. Because the medial meniscus posterior root occupies the same posterior tibial region, variations in footprint orientation may correspond to differences in the local attachment geometry of the posterior root. Such differences could potentially influence the distribution of tensile and shear forces across the root attachment during axial loading. However, this proposed mechanism remains hypothetical. PCL-FPA may therefore represent a distinct sagittal-plane morphometric characteristic of the posterior tibial attachment region rather than a direct measure of meniscal root biomechanics. The association between PCL-FPA and MMPRT should consequently be regarded as hypothesis-generating. Further anatomical and cadaveric biomechanical studies are required to determine whether PCL-FPA is directly related to medial meniscus posterior root attachment geometry or loading characteristics.

The combined model incorporating varus alignment, LPTS, and PCL-FPA demonstrated greater discriminative performance than any individual parameter, with an AUC of 0.885 compared with 0.790 for the best-performing individual parameter. This finding suggests that these variables may capture complementary morphometric characteristics associated with MMPRT. Varus alignment reflects coronal-plane medial compartment loading, LPTS may provide information related to tibial rotational biomechanics, and PCL-FPA may reflect posterior tibial attachment geometry in the sagittal plane. The ROC-derived cutoff values should be regarded as exploratory rather than clinically validated thresholds because they were derived from a single-center cohort and require external validation before clinical application. Nevertheless, the combined morphometric profile may help characterize knees with morphological features associated with degenerative MMPRT and may prompt closer evaluation of the posterior root on MRI.

A considerable proportion of previous studies have included patients with concomitant ACL pathology or have used patients with other meniscal pathologies as controls. ACL pathology is associated with altered tibiofemoral kinematics and meniscal loading and may therefore influence the observed relationships between tibial morphology and meniscal pathology.[16] Although obesity, female sex, advanced age, and varus alignment have been reported as factors associated with degenerative MMPRT,[17] evaluating morphometric parameters specifically in an isolated degenerative, ACL-intact population provides a more homogeneous assessment of these anatomical associations. The clinical importance of the medial meniscus posterior root is further supported by contemporary treatment strategies, including root repair combined with meniscal centralization in selected patients with meniscal extrusion.[18] The systematic exclusion of ACL pathology and the use of one-to-one age- and sex-matched controls constitute important strengths of the present study.

This study has several limitations. First, its retrospective, single-center design and relatively limited sample size may restrict the generalizability of the findings. Second, the control group comprised patients evaluated for nonspecific anterior knee pain rather than asymptomatic individuals. Although none had meniscal root pathology, this group may not fully represent a healthy population and may introduce selection bias. Third, although advanced osteoarthritis (Kellgren–Lawrence grade 3–4) was an exclusion criterion, individual KL grades were not systematically recorded because of the retrospective design. Therefore, residual differences in early osteoarthritic changes between the groups cannot be excluded and may have influenced parameters such as varus alignment and the observed associations. Fourth, BMI is a recognized factor associated with MMPRT; however, height and weight were not consistently available in the medical records, and BMI therefore could not be included in the regression analysis. Its potential confounding effect on the observed associations cannot be excluded. Fifth, PCL-FPA is a newly defined parameter whose biomechanical validity has not yet been established. In addition, the right-skewed distribution of LPTS values warrants caution when interpreting this parameter. The ROC-derived cutoff values should be considered exploratory and require external validation before clinical use. MMPRT was

confirmed arthroscopically in some patients and diagnosed by MRI alone in others, which may have introduced diagnostic heterogeneity. Furthermore, medial meniscal extrusion, which is closely associated with MMPRT and medial compartment overload, was not systematically assessed. The combined model was not externally validated, and the cross-sectional case-control design, without longitudinal follow-up, precludes interpretation of the identified parameters as predictors of future MMPRT development. Prospective multicenter studies incorporating BMI, standardized osteoarthritis grading, and biomechanical validation of PCL-FPA are warranted.

CONCLUSION

Varus alignment, increased lateral posterior tibial slope, and decreased PCL footprint angle were independently associated with isolated degenerative medial meniscus posterior root tears. MPTS was not significantly associated with MMPRT in this ACL-intact cohort. Increased LPTS may reflect alterations in tibial rotational biomechanics associated with MMPRT, whereas PCL-FPA may represent a distinct morphometric characteristic of the posterior tibial attachment region. The combined assessment of mechanical alignment, LPTS, and PCL-FPA may improve characterization of the morphometric profile associated with isolated degenerative MMPRT. Because PCL-FPA is a newly defined parameter, its anatomical and biomechanical relevance requires further validation in prospective and biomechanical studies.

DECLARATIONS

Ethics Committee Approval: This study was approved by the Ethics committee of Necmettin Erbakan University Faculty of Medicine (27.02.2026 - 236).

Informed Consent: The requirement for informed consent was waived by the Ethics Committee due to the retrospective study design.

Conflict of Interest: The authors declared no conflict of interest.

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Peer-review: Externally peer-reviewed.

ABBREVIATIONS

ACL: Anterior cruciate ligament

AUC: Area under the curve

CI: Confidence interval

ICC: Intraclass correlation coefficient

LPTS: Lateral posterior tibial slope

MMPRT: Medial meniscus posterior root tear

MPTS: Medial posterior tibial slope

MRI: Magnetic resonance imaging

OR: Odds ratio

PCL: Posterior cruciate ligament

PCL-FPA: PCL footprint angle

ROC: Receiver operating characteristic

SD: Standard deviation

REFERENCES

1. Monson JK, LaPrade RF. Posterior medial meniscus root tears: clinical implications, surgical management, and post-operative rehabilitation considerations. Int J Sports Phys Ther 2025;20:127–36. [CrossRef]
2. Kından Baltacı P, Toker M, Ozbek EA. Meniscus root tears: current concepts in anatomy, diagnosis, and treatment strategies. Sports Traumatol Arthrosc 2025;2:134–41. [CrossRef]
3. Allaire R, Muriuki M, Gilbertson L, Harner CD. Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. J Bone Joint Surg Am 2008;90:1922–31. [CrossRef]
4. Graden N, Ina J, Cabarcas B, Tagliero AJ, Krych A. Medial meniscus root tears: mechanics, management, and techniques. Ann Jt 2025;10:40. [CrossRef]
5. Foreman SC, Liu Y, Nevitt MC, Neumann J, Joseph GB, Lane NE, et al. Meniscal root tears and extrusion are significantly associated with the development of accelerated knee osteoarthritis: data from the osteoarthritis initiative. Cartilage 2021;13:239S–48S. [CrossRef]
6. Dzidzishvili L, Allende F, Allahabadi S, Mowers CC, Cotter EJ, Chahla J. Increased posterior tibial slope is associated with increased risk of meniscal root tears: a systematic review. Am J Sports Med 2024;52:3427–35. [CrossRef]
7. Oeding JF, Dean MC, Hevesi M, Chahla J, Krych AJ. Steeper slope of the medial tibial plateau, greater varus alignment, and narrower intercondylar distance and notch width

increase risk for medial meniscus posterior root tears: a systematic review. Arthroscopy 2025;41:3172–83.e3. [CrossRef]

8. Johannsen AM, Civitarese DM, Padalecki JR, Goldsmith MT, Wijdicks CA, LaPrade RF. Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci. Am J Sports Med 2012;40:2342–7. [CrossRef]
9. Benjamin M, Ralphs JR. Fibrocartilage in tendons and ligaments--an adaptation to compressive load. J Anat 1998;193:481–94. [CrossRef]
10. Anderson CJ, Ziegler CG, Wijdicks CA, Engebretsen L, LaPrade RF. Arthroscopically pertinent anatomy of the anterolateral and posteromedial bundles of the posterior cruciate ligament. J Bone Joint Surg Am 2012;94:1936–45. [CrossRef]
11. Hudek R, Schmutz S, Regenfelder F, Fuchs B, Koch PP. Novel measurement technique of the tibial slope on conventional MRI. Clin Orthop Relat Res 2009;467:2066–72. [CrossRef]
12. Melugin HP, Brown JR, Hollenbeck JFM, Fossum BW, Whalen RJ, Ganokroj P, et al. Increased posterior tibial slope increases force on the posterior medial meniscus root. Am J Sports Med 2023;51:3197–203. [CrossRef]
13. El Kayali MKD, Moewis P, Bartek B, Scheffler S, Boeth H, Winkler T, et al. Influence of the medial and lateral posterior tibial slope on anterior tibial translation during gait in anterior cruciate ligament-deficient knees. Orthop J Sports Med 2025;13:23259671251387352. [CrossRef]
14. Sevim OF, Afacan MY, Kayaalp ME. Posterior tibial slope-modifying osteotomies: current concepts in biomechanics, indications, surgical techniques and outcomes. Sports Traumatol Arthrosc 2026;3:36–46. [CrossRef]
15. Hwang BY, Kim SJ, Lee SW, Lee HE, Lee CK, Hunter DJ, et al. Risk factors for medial meniscus posterior root tear. Am J Sports Med 2012;40:1606–10. [CrossRef]
16. Samuelsen BT, Aman ZS, Kennedy MI, Dornan GJ, Storaci HW, Brady AW, et al. Posterior medial meniscus root tears potentiate the effect of increased tibial slope on anterior cruciate ligament graft forces. Am J Sports Med 2020;48:334–40. [CrossRef]
17. Mundal K, Geeslin AG, Solheim E, Inderhaug E. Differences between traumatic and degenerative medial meniscus posterior root tears: a systematic review. Am J Sports Med 2025;53:228–33. [CrossRef]
18. Oner K, Aslan FG. Isolated root repair versus root repair combined with meniscal centralization for medial meniscus posterior root tears with extrusion: clinical and radiographic outcomes. Sports Traumatol Arthrosc 2026;3:16–22. [CrossRef]

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Case Report

Tourniquet-Free Knee Arthroscopy in a Patient with Clinical Features Suggestive of Klippel–Trénaunay Syndrome: A Case Report

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ABSTRACT

Klippel–Trénaunay syndrome (KTS) and related venous malformation disorders may complicate lower-extremity surgery because of abnormal venous circulation and the potential risks of bleeding and thromboembolic events. We report the case of a 43-year-old man with chronic left knee pain and lifelong enlargement and cyanotic discoloration of the affected lower extremity. Magnetic resonance imaging demonstrated a medial femoral condyle osteochondral lesion, a longitudinal tear of the posterior horn of the medial meniscus, a suprapatellar plica, and multiple dilated periarticular venous structures. Doppler ultrasonography showed a patent deep venous system without thrombosis but marked superficial venous dilatation and great saphenous vein reflux. Following vascular surgical evaluation, the clinical findings were considered suggestive of the KTS spectrum. Knee arthroscopy was therefore performed without pneumatic tourniquet inflation. Adequate visualization was maintained using gravity-assisted irrigation and meticulous radiofrequency hemostasis. The medial meniscal tear was repaired, the osteochondral lesion was treated with debridement and microfracture, and the suprapatellar plica was resected. No intraoperative or postoperative vascular or orthopedic complications occurred. At 6 months, the patient had regained full knee motion with substantial symptomatic improvement. This case suggests that tourniquet-free knee arthroscopy may be a feasible option for carefully selected patients with suspected venous malformations, provided appropriate preoperative vascular assessment and meticulous intraoperative hemostasis are employed.

Keywords: Klippel–Trénaunay syndrome, venous malformation, knee arthroscopy, tourniquet-free surgery, meniscal repair, osteochondral lesion.

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INTRODUCTION

Knee arthroscopy is a minimally invasive orthopedic surgical procedure widely used for the diagnosis and treatment of various intra-articular knee pathologies, including meniscal tears, chondral lesions, and synovial disorders.[1] Pneumatic tourniquets are frequently used during arthroscopic knee surgery to improve visualization and reduce intra-articular bleeding.[2] However, tourniquet use has been associated with several potential risks, including venous stasis, muscle and nerve injury, and thromboembolic complications.[3]

Chronic venous insufficiency and congenital vascular malformations are clinical conditions that may present with venous dilation, limb hypertrophy, and skin discoloration of the lower extremities.[4] Among these conditions, Klippel–Trénaunay syndrome (KTS) is a rare congenital vascular malformation characterized by the triad of capillary malformations, venous varicosities,

and soft tissue or bone hypertrophy of the affected limb.[5] Owing to abnormal venous circulation and vascular structures, surgical procedures involving the lower extremities in these patients require careful preoperative planning and individualized surgical strategies.[6]

In this report, we present a case of tourniquet-free knee arthroscopy performed in a patient with clinical findings suggestive of the Klippel–Trénaunay syndrome spectrum.

CASE REPORT

A 43-year-old male patient presented to our clinic with left knee pain that had persisted for approximately 1 year. His symptoms included limping while walking, difficulty with knee flexion, and pain during knee extension. The patient reported that discoloration and an increased circumference of the affected leg had been present since childhood. Additionally, he had undergone endovenous laser ablation for varicose veins approximately 2 years earlier. The patient was not receiving any regular medical treatment.

The patient had previously been evaluated at another center, where arthroscopic knee surgery had been recommended. However, the procedure was canceled intraoperatively after marked swelling and discoloration of the lower extremity were observed, and the patient was subsequently referred to our clinic for further evaluation.

Physical examination revealed no obvious deformity of the knee joint. However, the affected lower extremity demonstrated a noticeably larger circumference than the contralateral side, accompanied by cyanotic discoloration, particularly in the foot and crural regions (Fig. 1).

Circumference measurements obtained from standard anatomical landmarks showed:

- Mid-thigh: 57 cm (left) vs 50 cm (right)
- Knee level: 44 cm (left) vs 39 cm (right)
- Mid-calf: 39 cm (left) vs 34 cm (right)

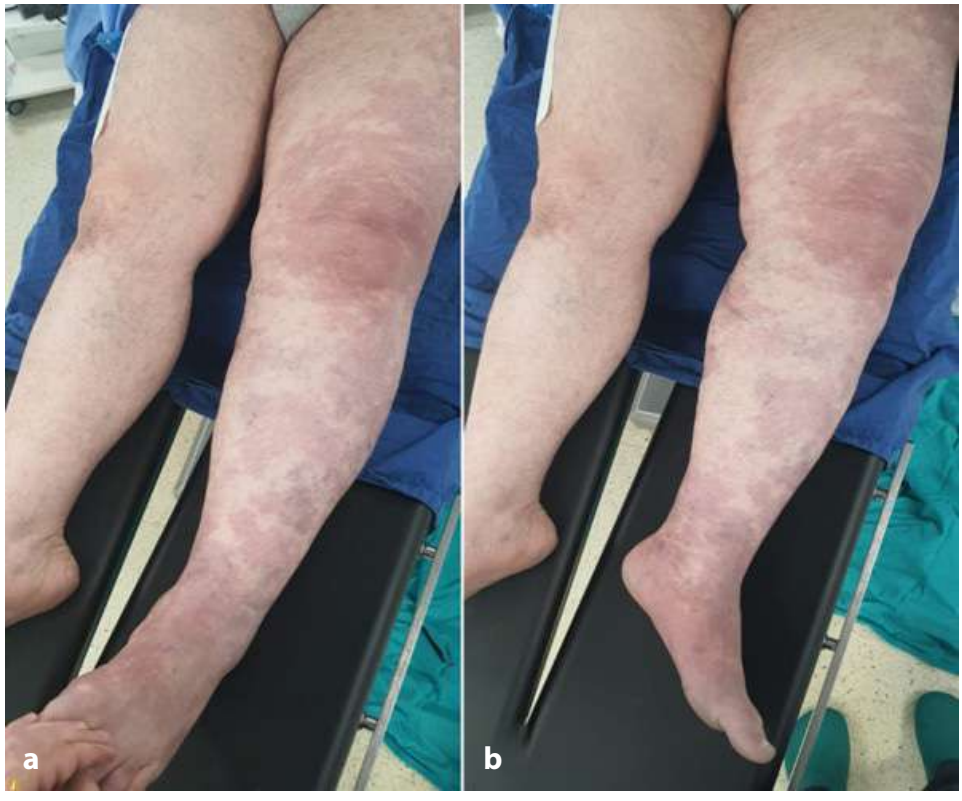

Figure 1. Preoperative clinical photographs of the affected lower extremity. **(a)** Anterior view of the left lower extremity demonstrating increased circumference, diffuse violaceous discoloration, and patchy vascular changes extending to the dorsum of the foot. **(b)** Bilateral comparison showing asymmetry in limb circumference and cutaneous vascular changes suggestive of a venous malformation spectrum.

Elevation of the limb resulted in a noticeable reduction in skin discoloration. No palpable venous masses were detected, and no limb-length discrepancy was observed.

Knee examination revealed a preserved range of motion, although pain was present, particularly during flexion. The suprapatellar ballottement test was positive. Medial joint-line tenderness was present, and the McMurray test was positive.

Plain radiographs of the knee demonstrated no osseous pathology (Fig. 2).

Magnetic resonance imaging (MRI) of the knee demonstrated cartilage irregularity compatible with an osteochondral lesion on the weight-bearing surface of the medial femoral condyle, accompanied by subchondral bone marrow edema. The lesion was estimated to measure approximately 1.5–2 cm in diameter. A band-like structure compatible with a suprapatellar synovial plica was also observed. Additionally, a longitudinal tear of the posterior horn of the medial meniscus was detected. Multiple dilated, serpiginous venous structures were noted within the subcutaneous tissues around the knee joint (Fig. 3).

Color Doppler ultrasonography performed to evaluate the venous system of the lower extremity demonstrated a patent deep venous system without evidence of thrombosis. Marked dilation of the superficial venous structures and reflux within the great saphenous vein were detected. These findings were consistent with chronic superficial venous insufficiency. Following consultation with the vascular surgery department, the patient's clinical presentation was considered suspicious for the Klippel–Trénaunay syndrome spectrum. Advanced venous imaging was not performed because Doppler ultrasonography demonstrated a patent deep venous system, and the vascular surgery team did not recommend further investigation.

Based on the preoperative evaluation, arthroscopic knee surgery was planned.

Surgical Technique

The patient was placed in the supine position under spinal anesthesia. A pneumatic tourniquet was placed proximally on the lower extremity; however, owing to the existing venous pathology, the procedure was performed without inflating the tourniquet. The knee was positioned at approximately 90° of flexion, and a lateral post was used.

Arthroscopic evaluation was performed using a 30° arthroscope through standard anterolateral and anteromedial portals. Joint irrigation was performed using normal saline delivered via a gravity-flow system, with a total irrigation volume of approximately 6,000 mL. The total operative time, defined as the duration from the initial incision to wound closure, was 36 minutes. Despite the absence of tourniquet inflation, satisfactory visualization was maintained throughout

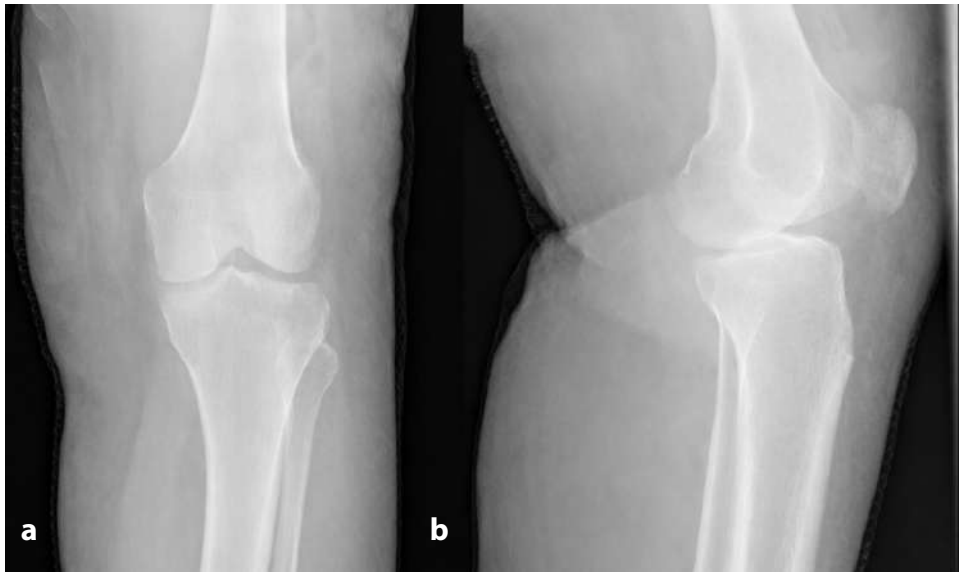

Figure 2. Preoperative knee radiographs of the affected limb. **(a)** Anteroposterior view demonstrating preserved joint alignment without apparent osseous abnormality. **(b)** Lateral view showing intact joint architecture without signs of fracture or advanced degenerative changes.

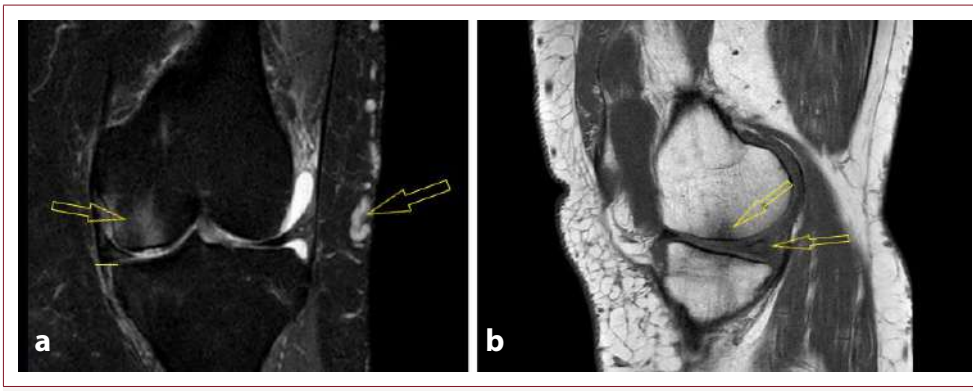

Figure 3. Magnetic resonance imaging of the knee. **(a)** Coronal fat-suppressed image demonstrating an osteochondral lesion with subchondral bone marrow edema on the weight-bearing surface of the medial femoral condyle (arrow), medial meniscal extrusion (line), and multiple dilated serpiginous venous structures within the periarticular soft tissues suggestive of a venous malformation (arrow). **(b)** Sagittal image demonstrating an osteochondral lesion of the medial femoral condyle (arrow) and a longitudinal tear of the posterior horn of the medial meniscus (arrow).

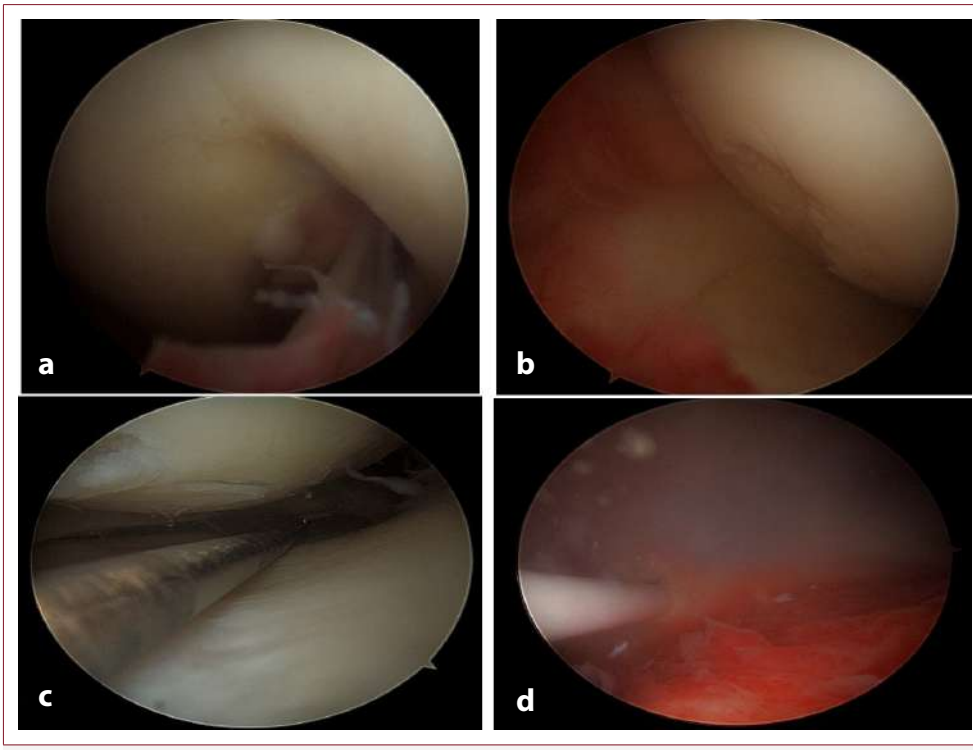

Figure 4. Arthroscopic findings during knee arthroscopy. **(a)** Initial diagnostic arthroscopic view demonstrating the ligamentum mucosum (infrapatellar plica). **(b)** Osteochondral lesion located on the weight-bearing surface of the medial femoral condyle. **(c)** Probe confirming a vertical longitudinal tear of the posterior horn of the medial meniscus in the red-red zone. **(d)** Arthroscopic appearance of a complete suprapatellar plica.

the procedure through continuous irrigation and meticulous hemostasis using radiofrequency coagulation when necessary.

Arthroscopic examination initially demonstrated the ligamentum mucosum (infrapatellar plica) (Fig. 4a). An Outerbridge grade III osteochondral lesion measuring approximately 2 × 2 cm was identified on the weight-bearing surface of the medial femoral condyle (Fig. 4b). Additionally, a vertical longitudinal tear of the posterior horn of the medial meniscus located in the red-red zone was observed (Fig. 4c), together with a complete suprapatellar plica (Fig. 4d).

The meniscal tear was first repaired using an all-inside technique (Fig. 5a). The osteochondral lesion was then debrided, and microfracture was performed by creating perforations approximately 3–4 mm apart in the subchondral bone using a microfracture awl (Fig. 5b). Following microfracture, bleeding and the release of bone marrow elements from the subchondral bone were observed. The suprapatellar plica was resected using a radiofrequency probe and shaver (Fig. 5c).

No intraoperative complications occurred.

Postoperative Follow-up

Postoperatively, the patient was mobilized using crutches without weight-bearing on the operated extremity for 4 weeks. Knee range-of-motion exercises were initiated early in the postoperative period. Partial weight-bearing was allowed in the fourth postoperative week, and full weight-bearing was permitted at approximately 6 weeks.

For deep vein thrombosis prophylaxis, low-molecular-weight heparin was administered for 4 weeks, and the patient was advised to wear anti-embolism stockings for 45 days.

At the 6-month follow-up, the patient demonstrated a full range of knee motion and reported a significant reduction in knee pain. No venous or orthopedic complications were observed during follow-up.

DISCUSSION

Lower extremity surgical procedures in patients with venous malformations or Klippel–Trénaunay syndrome (KTS) spectrum may present significant challenges in surgical planning.[7] Abnormal venous circulation in these patients may increase

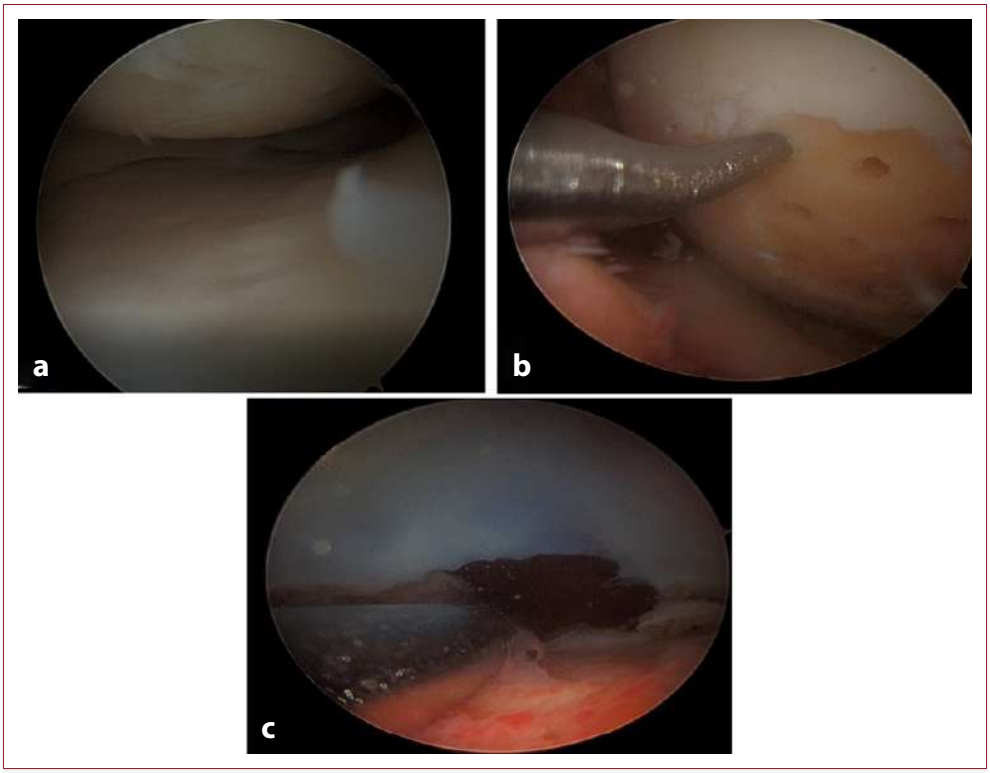

Figure 5. Arthroscopic images demonstrating the surgical procedures. **(a)** Medial meniscus after arthroscopic repair, showing restoration of the meniscal contour. **(b)** Microfracture of the osteochondral lesion using a microfracture awl. **(c)** Resection of the suprapatellar plica using a shaver.

the risks of intraoperative bleeding and thromboembolic complications.

Klippel–Trénaunay syndrome is a rare congenital vascular malformation characterized by the classic triad of capillary malformations, venous varicosities, and limb hypertrophy.[8] However, the clinical presentation may vary considerably among patients, and the complete triad is not always present simultaneously.[9] Therefore, the diagnosis is often established based on a comprehensive evaluation of clinical findings and imaging studies.

The use of a pneumatic tourniquet during arthroscopic knee surgery is commonly preferred to improve visualization and reduce intra-articular bleeding.[2] However, tourniquet use has been associated with several potential complications, including venous stasis, muscle and nerve injury, and thromboembolic events.[3] In patients with underlying venous circulation disorders, tourniquet inflation may theoretically exacerbate venous congestion and increase the risk of thromboembolic complications.[10]

The management of patients with venous malformations or those within the KTS spectrum who undergo lower extremity surgery requires careful consideration of tourniquet use. Barbara et al.[11] reviewed 136 anesthetic procedures in patients with KTS and reported that tourniquet application did not consistently prevent substantial intraoperative blood loss, highlighting the variability of hemostatic responses in this population. Gloviczki et al.[12] emphasized that although tourniquet use may help reduce intraoperative bleeding in selected cases, the presence of abnormal venous anatomy and potential coagulation disturbances necessitates individualized surgical planning and a multidisciplinary approach. Furthermore, Catre et al.[13] reported a case of total knee arthroplasty in a patient with KTS in which significant intraoperative challenges, including synovial hyperplasia, vascular engorgement, and increased bleeding, were encountered despite tourniquet use, although satisfactory hemostasis was ultimately achieved.

Several studies have suggested that knee arthroscopy can be performed without tourniquet inflation without compromising visualization or operative time. Kirkley et al.[14] reported no significant differences in functional outcomes or operative time between the tourniquet and non-tourniquet groups in a prospective randomized trial of routine knee arthroscopy. Similarly, a meta-analysis by Zhang et al.[15] involving 471 patients found no significant differences in visualization or operative time between the two groups, suggesting that routine tourniquet use may not be necessary in knee arthroscopy.

Taken together, these findings suggest that tourniquet use in patients with venous malformations or within the KTS spectrum may not always ensure optimal hemostatic control. Therefore, alternative strategies, such as a tourniquet-free approach, may be considered in carefully selected patients; however, further evidence is needed to support its routine use.

In the present case, arthroscopic knee surgery was successfully performed without tourniquet inflation, and intra-articular bleeding did not compromise surgical visualization. Adequate visualization was maintained through continuous irrigation and careful hemostasis. Although this observation suggests that tourniquet-free arthroscopic knee surgery may be feasible in selected patients with venous pathology, the findings should be interpreted with caution given the single-case design.

A further limitation of this report is the absence of an objective assessment of intraoperative visualization quality. Visualization was assessed subjectively by the operating surgeon, and no validated scoring system was used. The use of standardized and objective measures in future studies would allow for a more rigorous evaluation of the tourniquet-free approach.

In addition, the absence of advanced vascular imaging may limit the precise characterization of the underlying vascular anomaly. Furthermore, the findings of this report are based on a single case and therefore may not be generalizable to broader patient populations.

CONCLUSION

This case suggests that arthroscopic knee surgery may be performed without tourniquet inflation in a patient with a suspected venous malformation spectrum when careful preoperative evaluation and meticulous intraoperative hemostasis are ensured. However, these findings should be interpreted with caution given the single-case design and the absence of a definitive diagnosis of Klippel–Trénaunay syndrome. Tourniquet-free knee arthroscopy may represent a potential surgical option in carefully selected patients; however, its safety and feasibility require further validation in larger case series. Accordingly, the findings of this report should be considered hypothesis-generating, and further studies involving larger patient populations are needed to better define the clinical applicability of this approach.

DECLARATIONS

Ethics Committee Approval: This is a case report, and therefore ethics committee approval was not required in accordance with institutional policies.

Informed Consent: Informed consent was obtained from the patient for publication of this case report and accompanying clinical images.

Conflict of Interest: The authors declared no conflict of interest.

Financial Disclosure: The authors declared that they have no relevant or material financial interests that relate to the research described in this paper.

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Author Contributions: Concept – OK; Design – OK; Supervision – OK; Resource – OK; Data Collection and/or Processing – OK, TY; Analysis and/or Interpretation – OK, TY; Literature Search – OK; Writing – OK, TY; Critical Reviews – OK. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

1. Dave U, Lewis EG, Ierulli VK, Saraf SM, Mulcahey MK. Deep vein thrombosis prophylaxis in patients who undergo knee arthroscopy: a systematic review. Knee Surg Relat Res 2024;36:44. [CrossRef]
2. Sharma JP, Salhotra R. Tourniquets in orthopedic surgery. Indian J Orthop 2012;46:377–83. [CrossRef]
3. Klenerman L. The tourniquet in surgery. J Bone Joint Surg Br 1962;44:937–43. [CrossRef]
4. Gloviczki P, Comerota AJ, Dalsing MC, Eklof BG, Gillespie DL, Gloviczki ML, et al. The care of patients with varicose veins and associated chronic venous diseases: clinical practice guidelines of the Society for Vascular Surgery and the American Venous Forum. J Vasc Surg 2011;53(5 Suppl):2S–48S. [CrossRef]
5. Jacob AG, Driscoll DJ, Shaughnessy WJ, Stanson AW, Clay RP, Gloviczki P. Klippel-Trénaunay syndrome: spectrum and management. Mayo Clin Proc 1998;73:28–36. [CrossRef]
6. Lee BB. Critical issues in management of congenital vascular malformation. Ann Vasc Surg 2004;18:380–92. [CrossRef]
7. Lee BB, Laredo J, Lee TS, Huh S, Neville R. Terminology and classification of congenital vascular malformations. Phlebology 2007;22:249–52. [CrossRef]
8. Klippel M, Trénaunay P. Du naevus variqueux ostéo-hypertrophique. Arch Gen Med (Paris) 1900;3:641–72.
9. Oduber CE, van der Horst CM, Hennekam RC. Klippel-Trenaunay syndrome: diagnostic criteria and hypothesis on etiology. Ann Plast Surg 2008;60:217–23. [CrossRef]
10. Horlocker TT, Hebl JR, Gali B, Jankowski CJ, Burkle CM, Berry DJ, et al. Anesthetic, patient, and surgical risk factors for neurologic complications after prolonged total tourniquet time during total knee arthroplasty. Anesth Analg 2006;102:950–5. [CrossRef]
11. Barbara DW, Wilson JL. Anesthesia for surgery related to Klippel-Trenaunay syndrome: a review of 136 anesthetics. Anesth Analg 2011;113:98–102. [CrossRef]
12. Gloviczki P, Driscoll DJ. Klippel-Trenaunay syndrome: current management. Phlebology 2007;22:291–8. [CrossRef]
13. Catre MG, Kolin A, Waddell JP. Total knee arthroplasty in Klippel-Trenaunay syndrome. Can J Surg 2005;48:494–5.
14. Kirkley A, Rampersaud R, Griffin S, Amendola A, Litchfield R, Fowler P. Tourniquet versus no tourniquet use in routine knee arthroscopy: a prospective, double-blind, randomized clinical trial. Arthroscopy 2000;16:121–6. [CrossRef]
15. Zhang Y, Li L, Wang J, Li ZH, Shi ZJ. Do patients benefit from tourniquet in arthroscopic surgeries of the knee? Knee Surg Sports Traumatol Arthrosc 2013;21:1125–30. [CrossRef]

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Review

Osteonecrosis of the Femoral Head: Current Concepts in Diagnosis, Staging and Treatment

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ABSTRACT

Osteonecrosis of the femoral head (ONFH) is a progressive disorder characterized by ischemia-induced death of the subchondral bone, most commonly affecting young and active individuals. More than one-third of patients have a history of corticosteroid use, while approximately 20% of cases are considered idiopathic. In the early stages, the disease may remain clinically asymptomatic; however, with progression, patients typically develop hip or groin pain accompanied by limitation of hip abduction and internal rotation. Treatment strategies are determined according to the stage of the disease and include conservative management, joint-preserving procedures, and salvage procedures. The aim of this review is to comprehensively summarize the etiology, pathophysiology, diagnostic methods, staging systems, and current treatment approaches for femoral head avascular necrosis.

Keywords: Avascular Necrosis, Bone Marrow Aspirate Concentrate, Biological Augmentation, Osteonecrosis of femoral head

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INTRODUCTION

Avascular necrosis, also known as osteonecrosis, aseptic necrosis, or ischemic bone necrosis, is a degenerative joint disorder characterized by the death of the subchondral components of bone. The condition primarily impacts the epiphyses of weight-bearing long bones.[1] Osteonecrosis of the femoral head (ONFH) is a subtype of osteonecrosis in which impaired blood supply to the femoral head, due to various etiologic factors, results in bone tissue death.[2] As ONFH is an ischemic process, it may lead to substantial pain and functional limitation, adversely affecting quality of life. It may also progress from joint degeneration to coxarthrosis in up to 20% of patients.[2-5]

ONFH predominantly affects young adults (mean age, 33-38 years).[3] In the United States, approximately 10,000-20,000 new cases are reported annually, and subchondral collapse may occur in up to 80% of patients who do not receive adequate treatment.[3,4] The most critical period in the management of ONFH is the pre-collapse stage. [2-4] The Japanese Investigation Committee (JIC) classification may help predict subchondral collapse, guide the selection of appropriate treatment modalities in the pre-collapse stage, and facilitate prognostication of treatment outcomes.[6-8] The primary aim of this narrative review is to comprehensively evaluate and summarize contemporary diagnostic approaches, staging systems, and modern treatment strategies tailored to different stages of ONFH.

Literature Search Strategy

This manuscript was designed as a narrative review aimed at summarizing the current

concepts in the diagnosis, staging, and treatment of osteonecrosis of the femoral head (ONFH). The relevant literature was identified through searches of major medical databases including PubMed/MEDLINE, Scopus, and Web of Science. Keywords such as "osteonecrosis of the femoral head", "avascular necrosis", "core decompression", "bone marrow aspirate concentrate", "stem cell therapy", and "hip arthroplasty" were used in various combinations. Priority was given to recent publications and high-quality studies addressing diagnostic strategies, staging systems, and contemporary treatment approaches. Reference lists of relevant articles were also screened to identify additional pertinent studies.

Etiology and Pathophysiology

More than one-third of patients with ONFH have a history of corticosteroid use. During the COVID-19 pandemic, an increased incidence of ONFH has been reported, with corticosteroid exposure identified as the major contributing factor. [9-11] Alcohol misuse is implicated in 20%-30% of cases, whereas the etiology remains idiopathic in approximately 21%.[9,11] Other associated causes include trauma (femoral head fractures and hip dislocation), metabolic disorders (Gaucher disease, hyperparathyroidism, Cushing disease, and gout), autoimmune diseases (systemic lupus erythematosus), hematologic disorders (sickle cell anemia, bone marrow transplantation, and other hemoglobinopathies), and Legg-Calvé-Perthes disease. [2,9,12]

The most widely accepted mechanism of ONFH development is disruption of subchondral blood flow.[2] All etiologic factors are thought to act through three principal pathways that cause ischemia of bone structures: vascular pathologies, microthrombi formation, and extravascular compression. [1,2,12] In post-traumatic ONFH, injury to the retinacular arteries-which are crucial for the superolateral blood supply of the femoral head-has been emphasized. [13] Corticosteroid use has been associated with diffuse vasoconstriction, reportedly independent of dose.[3] Regardless of the underlying etiology, histological evidence of bone marrow necrosis and osteocyte death typically becomes apparent 24-72 hours after the onset of ischemia. This is followed by the release of free fatty acids and calcium ions into the extracellular matrix and initiation of an inflammatory response.[3] With prolonged ischemia, microfractures develop in the acellular trabecular bone, rendering it unable to withstand even normal loading. The limited proliferative capacity of bone cells during repair, reduction and disruption of the subchondral vascular network, and marked macrophage activation contribute to impaired regeneration.[14]

Diagnostic and Staging Methods

Clinical Evaluation and Physical Examination

In the early stages of ONFH, patients may be asymptomatic. As the disease progresses, pain typically begins in the groin and may radiate to the trochanteric region, gluteal area, and thigh. At this stage, pain intensity may increase during activities such as walking or climbing stairs without a clear restriction in hip range of motion, and may decrease with rest. With further progression, resting pain may occur, and limitation in hip abduction and internal rotation may become prominent. In advanced stages, articular cartilage degeneration may develop, leading to increased pain severity and reduced range of motion. In the terminal stage, acetabular cartilage involvement occurs, and clinical osteoarthritis becomes more evident.[1,2,9,11]

Imaging Modalities

When ONFH is suspected, anteroposterior and frog-leg lateral radiographs should be obtained as initial imaging studies.[1,2] However, the sensitivity of plain radiography is low in early disease [2,15]; therefore, magnetic resonance imaging (MRI), single-photon emission computed tomography (SPECT), and bone scintigraphy may be more valuable for early diagnosis (Fig.1).[2]

On plain radiographs, early-stage disease may appear entirely normal; alternatively, radiolucent or sclerotic areas may be

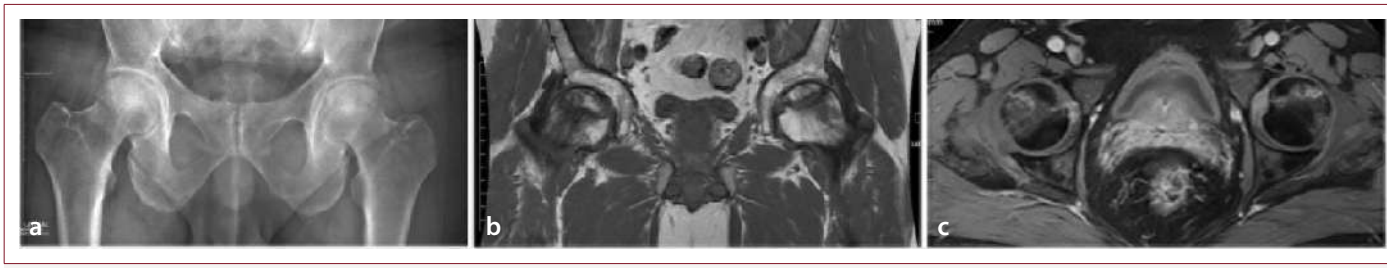

Figure 1. X-ray **(a)** and MRI **(b,c)** images of a 36-year-old male patient presenting with progressive worsening bilateral hip pain, without any underlying cause. **(a)** X-ray failed to demonstrate any pathological signs. **(b)** T1-weighted MRI image slice, showing well-defined lesions in the superior aspect of the femoral heads. **(c)** Bilateral bone marrow edema around the lesion in T2-weighted MRI image slice.

detected.[2,15] The pathognomonic "crescent sign" is observed in more advanced disease with subchondral collapse.[2,3,15] MRI is the most sensitive, specific, and widely used modality in ONFH and is considered the gold standard for imaging.[3,15] MRI provides clinically relevant information across all stages of the disease, including bone marrow changes; the size, location, and depth of the necrotic lesion; and the status of acetabular cartilage (Fig. 2). Moreover, MRI offers the advantage of monitoring treatment response.[1-3] The "double-line sign," described by Mitchell et al. [16] in 1987, remains highly specific for ONFH.[15,16] According to Stoica et al.[15], early-stage class A (fat-like) appearance corresponds to a normal marrow signal with a reactive sclerotic rim surrounding the lesion. Class B (blood-like) appearance may occur in the presence of subacute hemorrhage or insufficient inflammation/hyperemia. Class C (fluid-like) appearance is seen when inflammation, hyperemia, or lipid loss is prominent. When fibrosis and sclerosis predominate, class D (fibrous-like) appearance is observed, characterized by low signal intensity on all sequences.[15]

If contrast-enhanced MRI is not performed in early-stage disease, avascular foci may be overlooked. SPECT has been reported to be highly sensitive in detecting early avascular lesions and may be useful for early diagnosis.[17,18] When MRI is not feasible or provides insufficient information, SPECT can serve as an alternative.[15,17,18] On Tc-99m planar bone scintigraphy, a "donut sign," characterized by central hypoperfusion with peripheral reactive increased uptake, may be observed in the subacute stage of ONFH.[2,3]

Computed tomography (CT) is useful for evaluating morphological changes in ONFH (subchondral sclerosis, cystic areas, and collapse), but its sensitivity is limited in early stages. The "star sign," typically seen during the reparative phase, may be identified on CT. CT is particularly valuable for post-collapse evaluation and preoperative planning.[3,15]

Staging Systems

More than 16 classification systems have been described in the current literature for ONFH.[3,19] The Ficat-Arlet classification incorporates plain radiographs, MRI findings, and clinical features.[19] It consists of five stages (0-4). Stages 0-1 represent the "silent hip" phase with no radiographic findings. Stage 2 is characterized by sclerosis and cystic changes. Stage 3 includes subchondral collapse and the crescent sign. Stage 4 is the final stage, in which osteoarthritis and degenerative changes of the hip are present.[19]

The Steinberg classification, developed by incorporating bone scintigraphy findings, extends the Ficat-Arlet system by additionally considering lesion size and the extent of femoral head involvement.[20] This system includes seven stages, each subdivided into three categories based on the percentage of head involvement: A (<15%), B (15%-30%), and C (>30%).[20] Stage 0 indicates suspected AVN; stage I shows abnormalities on MRI or bone scintigraphy with normal radiographs; cystic and sclerotic changes on radiographs characterize stage II; and stages III-VI demonstrate radiographic signs of progressive osteonecrosis deterioration.[20]

The Association Research Circulation Osseous (ARCO) classification, updated in 2019, further evaluates lesion localization and has been suggested to be more reliable and clinically realistic than other systems; it is currently one of the most widely used classification methods.[21]

The JIC classification is among the most powerful systems for predicting collapse risk and guiding surgical planning in ONFH. The risk of subchondral collapse increases progressively from type A to type C2. Types A and B are associated with the lowest risk of collapse. Takashima et al.[22] reported that the JIC classification may be more effective than other systems in early-stage ONFH (Table 1).[8]

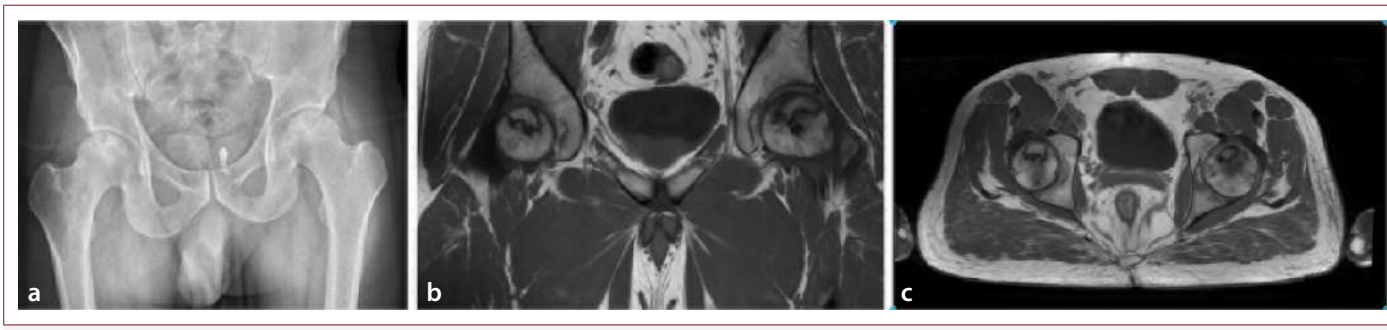

Figure 2. X-ray **(a)** and MRI **(b,c)** images of a 52-year-old male patient presenting with bilateral hip pain due to prior corticosteroid use. **(a)** X-ray demonstrated bilateral mixed sclerosis and cystic areas. **(b)** T1-weighted coronal and **(c)** T1-weighted axial slices showing well-defined anterosuperior lesions, indicating ONFH.

Table 1. Staging and classification systems used in ONFH

	Ficat-Arlet Classification		Steinberg Classification		ARCO Classification		JIC Classification
			Steinberg classification further grades extent of involvement as: A (<15%), B (15–30%), and C (>30%)		ARCO also incorporates lesion size (<15%, 15–30%, >30%) and location (medial, central, lateral), making it highly suitable for research and prognostic stratification.		The JIC system emphasizes location of necrosis and risk of collapse, rather than only disease stage.
0	Clinical symptoms: Asymptomatic X-ray: normal MRI: normal Bone scan: Decreased or heterogeneous uptake	0	Clinical symptoms: Asymptomatic X-ray: normal MRI: normal Bone scan: normal				
I	Clinical symptoms: Hip pain, activity-related X-ray: normal MRI: Bone marrow edema Bone scan: "Cold in hot" pattern	I	Clinical symptoms: Possible Pain X-ray: normal MRI: edema Bone scan: Abnormal Uptake	I	Clinical symptoms: Pain may be present X-ray: normal MRI: edema Bone scan: Abnormal uptake	A	Medial one-third of the weight-bearing area Low risk of collapse
II	Clinical symptoms: Persistent pain X-ray: Sclerosis, Cysts MRI: Well-defined necrotic area ± edema Bone scan: Increased peripheral uptake	II	Clinical symptoms: Hip Pain X-ray: Sclerosis, Cysts MRI: Necrotic lesion visible Bone scan: Increased uptake	II	Clinical symptoms: Progressive pain X-ray:Sclerosis/cysts, no collapse MRI: Clear demarcation of necrosis Bone scan: Increased uptake	B	Medial + central area Moderate risk of collapse
III	Clinical symptoms: Mechanical pain, limp X-ray: Crescent sign, subchondral fracture MRI: Subchondral collapse Bone scan: Intense increased uptake	III	Clinical symptoms: Mechanical pain Xray: Crescent sign MRI: Subchondral fracture Bone scan: Increased uptake	IIIA	Clinical symptoms: Mechanical pain X-ray: Subchondral fracture, collapse <2 mm MRI: Crescent sign, early deformity Bone scan: High uptake	C1	Extends laterally but not to acetabular edge High risk of collapse
				IIIB	Clinical symptoms: More severe symptoms X-ray: Collapse ≥2 mm MRI: Distorted femoral head contour Bone scan: High uptake	C2	Extends to the lateral acetabular edge Very high risk of collapse
IV	Clinical symptoms: Severe pain, stiffness X-ray: Femoral head collapse MRI: Deformity, cartilage degeneration Bone scan: Diffuse increased uptake	IV	Clinical symptoms:Functional limitation X-ray: Femoral head collapse MRI: Femoral head deformity Bone scan: Increased uptake	IV	Clinical symptoms: Advanced pain, limited motion X-ray: Secondary OA, acetabular changes MRI: Degenerative changes Bone scan: Diffuse increased uptake		

Table 1. Continued

Ficat-Arlet Classification	Steinberg Classification	ARCO Classification	JIC Classification
	V Clinical symptoms: Severe pain X-ray: Joint-space narrowing MRI: Secondary OA changes Bone scan: Diffuse increased uptake		
	VI Clinical symptoms: Severe disability X-ray: Advanced OA MRI: Advanced degenerative changes Bone scan: Diffuse increased uptake		

Contemporary Treatment Options

A broad range of treatment options is available for patients diagnosed with ONFH, ranging from conservative management to total hip arthroplasty. Subchondral collapse of the femoral head may occur in up to 80% of untreated patients.[3] Selection of the most appropriate treatment strategy depends on the patient's age, pain severity, lesion location, size and depth, comorbidities, and the presence of cartilage degeneration.[2,3] Outcomes are more favorable when treatment is initiated before femoral head collapse[2,3]; therefore, early diagnosis is the most critical step in the management of ONFH. It should be noted that ONFH secondary to sickle cell anemia, corticosteroid exposure, or immunosuppressive therapy may be associated with a higher risk of a poor prognosis.[2,3,4]

Treatment may be broadly categorized into three groups based on disease stage, lesion size, and patient age/activity level: conservative treatment methods, joint-preserving procedures, and salvage procedures.

Conservative Treatment Methods

The primary goal of conservative management, particularly in early-stage disease (ARCO stages I and II), is to prevent subchondral collapse. Commonly used approaches include activity modification, protected weight-bearing, hyperbaric oxygen therapy (HBOT), pharmacological treatments (e.g., iloprost [PGI2], bisphosphonates, and anticoagulants), and extracorporeal shockwave therapy (ESWT).[3,4,23] Among pharmacological agents, bisphosphonates and deferoxamine have been shown to reduce steroid-induced bone resorption and enhance regeneration.[24] Iloprost (PGI2) has also been reported to be effective when used alone or in combination with joint-preserving procedures in early-stage ONFH (ARCO stages I and II).[25]

Currie et al.[26] reported outcomes of 30 years of experience with HBOT and demonstrated that it significantly prevented progression of ONFH. Guo et al.[27] showed that anticoagulant therapy may be effective in idiopathic ONFH; however, they suggested that it does not provide a protective effect in secondary ONFH. ESWT has been reported to be more effective than core decompression, and the addition of HBOT and bisphosphonates may further enhance the effects of ESWT.[28] Overall, the combined use of conservative modalities is considered reasonable, and these strategies may also serve as adjuncts to surgical treatment in appropriately selected patients.

Joint-Preserving Surgical Procedures

Core Decompression (mechanism and current modifications)

The principal objective of core decompression is to reduce intraosseous pressure within the femoral head and thereby improve perfusion.[3,4] It is the most commonly performed primary treatment option for patients without subchondral collapse, and its effectiveness has been enhanced by combining it with biological and/or cellular therapies.[3,4,29]

Conventional single-track drilling has been used historically for core decompression.[30] Recently, multiple drilling techniques have gained popularity due to lower risks of hip fracture, local wound complications, and revision surgery.[30,31] Additionally, retro-drilling with an expandable reamer through a single core is gaining popularity in terms of reducing complications and allowing application of adjunct biological augmentations.[29] (Fig. 3) Following either technique, avoidance of weight-bearing for 6 weeks and refraining from high-demand activities for up to 12 months are generally recommended.[3,4]

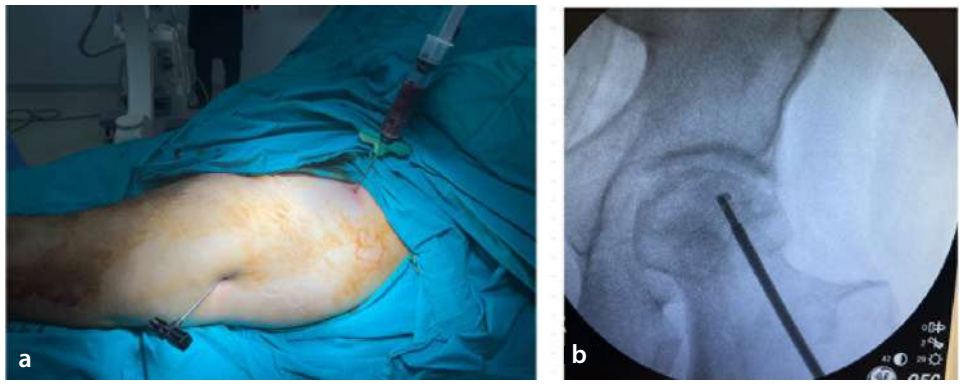

Figure 3. (a) Obtaining BMAC and core decompression using retrograde drill is possible in a minimally invasive manner. **(b)** Retrograde drilling of the femoral head to perform debridement and core decompression of the osteonecrotic lesion.

Grafting Techniques

Non-vascularized bone grafting

Non-vascularized bone grafting has been used for decades to prevent subchondral collapse in ONFH. Surgical techniques such as the Phemister, lightbulb, and trapdoor procedures have been described to support and repair the subchondral bone. [3] Mei et al.[32], in a study comparing allogenic non-vascularized bone grafting with core decompression, reported better femoral head survival in the core decompression group. With devices for mosaicplasty, cylindrical autologous grafts taken from the iliac crest can be utilized for filling the defect after core decompression with ease (Fig. 4).

Vascularized bone grafting (VFG)

Vascularized fibular grafting (VFG) has been recommended as a hip-preserving option in selected patients with ARCO stages I-III disease, particularly in cases of failed core decompression, collapse <3 mm, and femoral head involvement <50%.[3,4] Yoo et al.[33] reported acceptable long-term outcomes at a mean follow-up of 13.5 years after VFG.

Biological Augmentation

Despite the availability of multiple treatment options, no universally accepted gold-standard treatment for ONFH has yet been established. In recent years, interest has increased in orthobiologic therapies-such as mesenchymal stem cells (MSCs), bone marrow aspirate concentrate (BMAC), hematopoietic stem cells, endothelial progenitor cells, platelet-derived products, and growth factors-to prevent collapse and delay or avoid total hip arthroplasty.[5]

Bone marrow aspirate concentrate (BMAC) and stem cell applications

Several studies have suggested that autologous bone marrow-derived mesenchymal therapies and BMAC, used as an adjunct

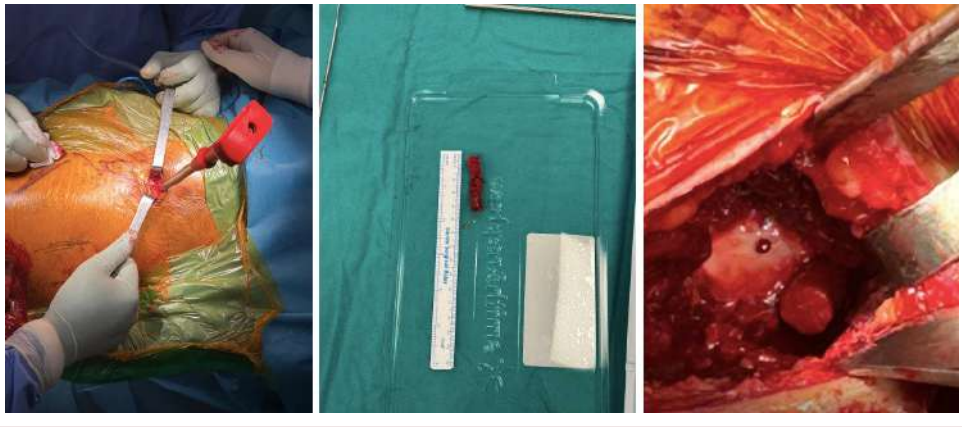

Figure 4. Cylindrical cancellous bone grafts harvested from the iliac crest are inserted through the tunnel created on the lateral aspect of the proximal femur.

to core decompression, may be more effective in preventing the need for total hip arthroplasty and improving clinical outcomes.[5,34,35] BMAC is an autologous bone marrow-derived cellular concentrate typically obtained via iliac crest aspiration and contains MSCs, hematopoietic stem cells, endothelial progenitor cells, platelets, growth factors, and cytokines. Because it is minimally invasive, relatively easy to apply, and supported by preclinical in vitro and in vivo studies demonstrating efficacy in osteonecrosis, BMAC has been increasingly used in combination with core decompression and has become progressively more popular in recent years.[5,29,35]

In addition to decompression, BMAC may support recovery after osteonecrosis through osteoconductive and osteoinductive effects. Zaffagnini et al.[5] found that BMAC was more effective than other orthobiologic strategies in reducing the need for total hip arthroplasty. Wang et al. [36] concluded that MSC therapy was the most effective approach for reducing the need for total hip arthroplasty, followed by BMAC therapy.

Platelet-rich plasma (PRP) and growth factors

Autologous platelet-rich plasma contains high concentrations of platelets and various growth factors (PDGF, TGF-β, FGF, EGF, VEGF), and has been shown to influence tissue repair as well as MSC proliferation and differentiation. In ONFH, PRP is thought to stimulate angiogenesis and osteogenesis and to exert beneficial effects by inhibiting inflammatory reactions and apoptosis. Therefore, PRP has been recommended as an adjunct to core decompression in early-stage disease (ARCO stages I and II).[37] Houdek et al. suggested that, in patients without subchondral collapse and after cessation of corticosteroid use, combining BMAC and PRP with core decompression may represent the most appropriate treatment strategy.[38]

Osteotomies

The goal of osteotomy in ONFH is to redistribute load across the femoral head to prevent subchondral collapse. Intertrochanteric (valgus/varus) and transtrochanteric (rotational) osteotomies have been described. Osteotomy may be considered in selected patients younger than 40 years with BMI <24, ARCO stages II-III, JIC type B lesions, adequate viable bone stock (angle >150° between the central vertical line and the lateral edge of the necrotic region on coronal MRI), no acetabular pathology, and preserved hip range of motion.[3,4,39]

Salvage Procedures

In advanced-stage ONFH (ARCO stage IV) that remains symptomatic despite conservative and joint-preserving interventions, arthroplasty may provide substantial pain relief and functional improvement. Because many patients are young and active, thorough counseling regarding potential complications of arthroplasty is essential.[2,4]

Total hip arthroplasty

With advances in bearing surfaces-particularly ceramic-on-ceramic and highly cross-linked polyethylene (HXLPE)-ceramic articulations-implant survivorship has improved. Zhang et al. reported that, among patients undergoing total hip arthroplasty (THA) for ONFH, medical complications increased with age, whereas revision rates and surgical complication rates decreased. Overall complication rates were higher in ONFH patients than in those with osteoarthritis (OA).[40] Tanaka et al.[41], in a nationwide database study including approximately 25,000 patients, reported significantly higher rates of hip dislocation, mortality, and additional complications after THA performed for ONFH compared with THA performed for OA. In contrast, Osawa et al. reported comparable 10-year survivorship and complication rates between THA performed for OA and THA performed for ONFH when matched for age and sex.[42]

Hip resurfacing arthroplasty

Hip resurfacing has been described as an alternative to conventional THA for young patients with ONFH, with the potential benefits of bone stock preservation and excellent short-term outcomes.[43] However, none of the hip resurfacing implants met the 10-year survivorship benchmark, and concerns about pseudotumor formation, femoral neck fractures, and metal-ion toxicity associated with metal-on-metal bearings have led to a decline in its use in recent years.[44,45]

CONCLUSION

ONFH remains a frequently debated condition in orthopedic practice, particularly with respect to etiology and treatment decision-making. Treatment selection should be guided by patient age, activity level, and the presence or absence of femoral head collapse and/or articular cartilage degeneration. In patients without subchondral collapse, combined application of core decompression with BMAC and/or PRP, along with adjunctive hyperbaric oxygen therapy, may be considered as part of a multidisciplinary joint-preserving strategy.

DECLARATIONS

Ethics Committee Approval: This is a review, and therefore ethics committee approval was not required in accordance with institutional policies.

Informed Consent: Informed consent was not deemed necessary for this study.

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Peer-review: Externally peer-reviewed.

ABBREVIATIONS

ARCO: Association Research Circulation Osseous

AVN: Avascular necrosis

BMAC: Bone marrow aspirate concentrate

BMI: Body mass index

CT: Computed tomography

EGF: Epidermal growth factor

ESWT: Extracorporeal shock wave therapy

FGF: Fibroblast growth factor

HBOT: Hyperbaric oxygen therapy

HXLPE: Highly cross-linked polyethylene

JIC: Japanese Investigation Committee

MRI: Magnetic resonance imaging

MSC: Mesenchymal stem cell

OA: Osteoarthritis

ONFH: Osteonecrosis of the femoral head

PDGF: Platelet-derived growth factor

PGI2: Prostacyclin

PRP: Platelet-rich plasma

SPECT: Single-photon emission computed tomography

TGF-β: Transforming growth factor beta

THA: Total hip arthroplasty

VEGF: Vascular endothelial growth factor

VFG: Vascularized fibular grafting

REFERENCES

1. Matthews AH, Davis DD, Fish MJ, Stitson D. Avascular Necrosis. 2023. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026
2. Barney J, Piuzzi NS, Akhondi H. Femoral Head Avascular Necrosis. [Updated 2023 Jul 3]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK546658/.
3. Petek D, Hannouche D, Suva D. Osteonecrosis of the femoral head: pathophysiology and current concepts of treatment. EFORT Open Rev 2019;4:85-97. [Crossref]
4. Liu N, Zheng C, Wang Q, Huang Z. Treatment of non-traumatic avascular necrosis of the femoral head (Review). Exp Ther Med 2022;23:321. [Crossref]
5. Zaffagnini M, Boffa A, Andriolo L, Raggi F, Zaffagnini S, Filardo G. Orthobiologic therapies delay the need for hip arthroplasty in patients with avascular necrosis of the femoral head: A systematic review and survival analysis. Knee Surg Sports Traumatol Arthrosc 2025;33:1112-27. [Crossref]
6. Sugano N, Atsumi T, Ohzono K, Kubo T, Hotokebuchi T, Takaoka K. The 2001 revised criteria for diagnosis, classification, and staging of idiopathic osteonecrosis of the femoral head. J Orthop Sci 2002;7:601-5. [Crossref]
7. Kuroda Y, Tanaka T, Miyagawa T, Kawai T, Goto K, Tanaka S, Matsuda S, Akiyama H. Classification of osteonecrosis of the femoral head: Who should have surgery? Bone Joint Res 2019;8:451-8. [Crossref]
8. Akgün E, Kaya İ, Topçuoğlu A, Tepedelenlioğlu HE, Fırat A. The effect of the Japanese Investigation Committee classification on hip joint survival after core decompression therapy in pre-collapsed avascular necrosis of the femoral head. TJCL 2024;15:455-62. [Crossref]
9. Konarski W, Poboży T, Śliwczyński A, Kotela I, Krakowiak J, Hordowicz M, et al. Avascular Necrosis of Femoral Head-Overview and Current State of the Art. Int J Environ Res Public Health 2022;19:7348. [Crossref]
10. Veizi E, Erdoğan Y, Sezgin BS, Karaman Y, Kılıçarslan K, Fırat A. The painful joint after COVID-19 treatment: A study on joint osteonecrosis following COVID-19-related corticosteroid use. Jt Dis Relat Surg 2023;34:75-83. [Crossref]
11. Khanchandani P, Narayanan A, Naik AA, Kannan V, Pradhan SS, Srimadh Bhagavatham SK, et al. Clinical Characteristics, Current Treatment Options, Potential Mechanisms, Biomarkers, and Therapeutic Targets in Avascular Necrosis of Femoral Head. Med Princ Pract 2024;33:519-36. [Crossref]
12. Bülbül AM, Korkmaz O, Yıldırım AÖ. Avasküler nekroz: etiyolojisi ve patofizyolojisi. TOTBİD Dergisi 2020;19:849-54. [Crossref]
13. Rego P, Mascarenhas V, Collado D, Coelho A, Barbosa L, Ganz R. Arterial Topographic Anatomy Near the Femoral Head-Neck Perforation with Surgical Relevance. J Bone Joint Surg Am 2017;99:1213-21. [Crossref]
14. Vicaş RM, Bodog FD, Fugaru FO, Grosu F, Badea O, Lazăr L, Cevei ML, Nistor-Cseppento CD, Beiuşanu GC, Holt G,

Voiță-Mekereş F, Buzlea CD, Țica O, Ciursaş AN, Dinescu SN. Histopathological and immunohistochemical aspects of bone tissue in aseptic necrosis of the femoral head. Rom J Morphol Embryol 2020;61:1249-58. [Crossref]

15. Stoica Z, Dumitrescu D, Popescu M, Gheonea I, Gabor M, Bogdan N. Imaging of avascular necrosis of femoral head: familiar methods and newer trends. Curr Health Sci J 2009;35:23-8. Epub 2009. [CrossRef]
16. Mitchell DG, Rao VM, Dalinka MK, Spritzer CE, Alavi A, Steinberg ME, et al. Femoral head avascular necrosis: correlation of MR imaging, radiographic staging, radionuclide imaging, and clinical findings. Radiology 1987;162:709-15. [Crossref]
17. Bharadwaj MS, Negi VS, Barathi D, Ponnusamy M. Utility of SPECT/CT in Non-Traumatic Osteonecrosis: Revisited with New Insights from a Prospective Diagnostic Study. Indian J Nucl Med. 2025;40:127-35 Epub 2025. [Crossref]
18. Iqbal B, Currie G. Value of SPECT/CT in the diagnosis of avascular necrosis of the head of femur: A meta-analysis. Radiography (Lond) 2022;28:560-4. [Crossref]
19. Jawad MU, Haleem AA, Scully SP. In brief: Ficat classification: avascular necrosis of the femoral head. Clin Orthop Relat Res 2012;470:2636-9. [Crossref]
20. Steinberg ME, Steinberg DR. Classification systems for osteonecrosis: an overview. Orthop Clin North Am 2004;35:273-83. [Crossref]
21. Koo KH, Mont MA, Cui Q, Hines JT, Yoon BH, Novicoff WM, et al. The 2021 Association Research Circulation Osseous Classification for Early-Stage Osteonecrosis of the Femoral Head to Computed Tomography-Based Study. J Arthroplasty 2022;37:1074-82. Epub 2022 Feb 11. [Crossref]
22. Takashima K, Sakai T, Hamada H, Takao M, Sugano N. Which Classification System Is Most Useful for Classifying Osteonecrosis of the Femoral Head? Clin Orthop Relat Res 2018;476:1240-9. [Crossref]
23. Moya-Angeler J, Gianakos AL, Villa JC, Ni A, Lane JM. Current concepts on osteonecrosis of the femoral head. World J Orthop 2015;6:590-601. [Crossref]
24. Sheng H, Lao Y, Zhang S, Ding W, Lu D, Xu B. Combined Pharmacotherapy with Alendronate and Desferoxamine Regulate the Bone Resorption and Bone Regeneration for Preventing Glucocorticoids-Induced Osteonecrosis of the Femoral Head. Biomed Res Int 2020;2020:3120458. [Crossref]
25. Claßen T, Becker A, Landgraeber S, Haversath M, Li X, Zilkens C, Krauspe R, Jäger M. Long-term Clinical Results after Iloprost Treatment for Bone Marrow Edema and Avascular Necrosis. Orthop Rev (Pavia) 2016;8:6150. [Crossref]
26. Currie JR, Gawthrope IC, Banham ND. The use of hyperbaric oxygen for avascular necrosis of the femoral head and femoral condyle: a single centre's experience over 30 years. Diving Hyperb Med 2024;54:92-6. [Crossref]
27. Guo P, Gao F, Wang Y, Zhang Z, Sun W, Jiang B, et al. The use of anticoagulants for prevention and treatment of osteonecrosis of the femoral head: A systematic review. Medicine (Baltimore) 2017;96:e6646. [Crossref]
28. Wang CJ, Cheng JH, Huang CC, Yip HK, Russo S. Extracorporeal shockwave therapy for avascular necrosis of femoral head. Int J Surg 2015;24:184-7. [Crossref]
29. Bozkurt M, Veizi E, Fırat N, Şahin A. Biological Augmentation With Retro-Drilling Core Decompression in Early Stage of Femoral Head Avascular Necrosis. Arthrosc Tech 2024;13:103093. [Crossref]
30. Dubé MD, Emara AK, Deren ME, Pasqualini I, Rullan PJ, Tidd J, et al. Techniques of core decompression in the treatment of idiopathic avascular necrosis of the femoral head. Arch Orthop Trauma Surg 2024;145:82. [Crossref]
31. Kang SY, Kim HS, Yoo JJ. Outcomes of Multiple Drilling for Osteonecrosis of the Femoral Head: A Retrospective Cohort Study With a Minimum 10-Year Follow-Up. J Arthroplasty 2025;40:S57-65. [Crossref]
32. Mei J, Jiang ZP, Pang LL, Huang Y, Gong Y, Zhu J, Zhang LW. Core decompression vs. allogenic non-vascularized bone grafting in patients with osteonecrosis of the femoral head. Front Surg 2023;10:1219835. [Crossref]
33. Yoo MC, Kim KI, Hahn CS, Parvizi J. Long-term followup of vascularized fibular grafting for femoral head necrosis. Clin Orthop Relat Res. 2008;466:1133-40. [Crossref]
34. Jeyaraman M, Muthu S, Jain R, Khanna M. Autologous bone marrow derived mesenchymal stem cell therapy for osteonecrosis of femoral head: A systematic overview of overlapping meta-analyses. J Clin Orthop Trauma. 2020;13:134-142. [Crossref]
35. Wang Z, Sun QM, Zhang FQ, Zhang QL, Wang LG, Wang WJ. Core decompression combined with autologous bone marrow stem cells versus core decompression alone for patients with osteonecrosis of the femoral head: A meta-analysis. Int J Surg 2019;69:23–31. [Crossref]
36. Wang X, Hu L, Wei B, Wang J, Hou D, Deng X. Regenerative therapies for femoral head necrosis in the past two decades: a systematic review and network meta-analysis. Stem Cell Res Ther 2024;15:21. [Crossref]
37. Han J, Gao F, Li Y, Ma J, Sun W, Shi L, Wu X, Li T. The Use of Platelet-Rich Plasma for the Treatment of Osteonecrosis of the Femoral Head: A Systematic Review. Biomed Res Int 2020;2020:2642439. [Crossref]
38. Houdek MT, Wyles CC, Smith JH, Terzic A, Behfar A, Sierra RJ. Hip decompression combined with bone marrow concentrate and platelet-rich plasma for corticosteroid-induced osteonecrosis of the femoral head: mid-

term update from a prospective study. Bone Jt Open 2021;2:926-31. [Crossref]

39. Lee YK, Lee B, Parvizi J, Ha YC, Koo KH. Which Osteotomy for Osteonecrosis of the Femoral Head and Which Patient for the Osteotomy? Clin Orthop Surg 2019;11:137-41. [Crossref]
40. Zhang Z, Chi J, Driskill E, Mont MA, Jones LC, Cui Q. Effect of Patient Age on Total Hip Arthroplasty Outcomes in Patients Who Have Osteonecrosis of the Femoral Head Compared to Patients Who Have Hip Osteoarthritis. J Arthroplasty 2024;39:1535-44. [Crossref]
41. Tanaka H, Tarasawa K, Mori Y, Kuriyama Y, Kawamata H, Fushimi K, et al. Does Osteonecrosis of the Femoral Head Increase Early Complication Rates After Total Hip Arthroplasty? A Japanese Nationwide Medical Claims Database Study. J Arthroplasty 2025;40:2053-9. Epub 2025. [Crossref]
42. Osawa Y, Seki T, Takegami Y, Kusano T, Makida K, Ishiguro N. Cementless total hip arthroplasty for osteonecrosis and osteoarthritis produce similar results at ten years follow-up when matched for age and gender. Int Orthop 2018;42:1683-8. Epub 2018. [Crossref]
43. Mont MA, Seyler TM, Marker DR, Marulanda GA, Delanois RE. Use of metal-on-metal total hip resurfacing for the treatment of osteonecrosis of the femoral head. J Bone Joint Surg Am 2006;88:90-7. [Crossref]
44. van der Weegen W, Hoekstra HJ, Sijbesma T, Bos E, Schemitsch EH, Poolman RW. Survival of metal-on-metal hip resurfacing arthroplasty: a systematic review of the literature. J Bone Joint Surg Br 2011;93:298-306. [Crossref]
45. Matharu GS, Pandit HG, Murray DW. Poor Survivorship and Frequent Complications at a Median of 10 Years After Metal-on-Metal Hip Resurfacing Revision. Clin Orthop Relat Res 2017;475:304-14. [Crossref]