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DIAGNOSTIC AND THERAPEUTIC DECISION-MAKING IN TIBIAL EMINENCE AVULSION FRACTURES OF THE ANTERIOR CRUCIATE LIGAMENT: A CONTEMPORARY REVIEW

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Abstract. Tibial eminence avulsion fractures represent intra-articular injuries involving the tibial insertion of the anterior cruciate ligament and are particularly characteristic of children and adolescents, although they may also occur in adults after high-energy trauma. Contemporary management requires assessment of fragment displacement, comminution, soft-tissue interposition, meniscal injury, skeletal maturity, and residual anterior instability. The modified Meyers–McKeever classification remains the most widely used radiographic system, while magnetic resonance imaging provides additional information about meniscal entrapment, chondral damage, associated ligament injury, and fracture morphology. Type I fractures are usually managed conservatively; type II injuries remain controversial and require assessment of reduction quality and soft-tissue interposition, whereas completely displaced type III and comminuted type IV fractures generally require operative fixation. Arthroscopic reduction and internal fixation enables direct visualization of the fracture bed and simultaneous treatment of associated intra-articular pathology.

Keywords: anterior cruciate ligament, tibial eminence, tibial spine, avulsion fracture, MRI, arthroscopy, suture fixation, screw fixation, knee instability.

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ДИАГНОСТИЧЕСКАЯ И ЛЕЧЕБНАЯ ТАКТИКА ПРИ ОТРЫВНЫХ ПЕРЕЛОМАХ МЕЖМЫЩЕЛКОВОГО ВОЗВЫШЕНИЯ БОЛЬШЕБЕРЦОВОЙ КОСТИ В ЗОНЕ ПРИКРЕПЛЕНИЯ ПЕРЕДНЕЙ КРЕСТООБРАЗНОЙ СВЯЗКИ: СОВРЕМЕННЫЙ ОБЗОР

Аннотация. Отрывные переломы межмыщелкового возвышения большеберцовой кости представляют собой внутрисуставные повреждения, затрагивающие область тибиального прикрепления передней крестообразной связки, и особенно характерны для детей и подростков, хотя могут встречаться и у взрослых после высокоэнергетической травмы. Современная лечебная тактика требует оценки степени смещения и многооскольчатости костного фрагмента, интерпозиции мягких тканей, повреждений менисков, скелетной зрелости пациента и остаточной передней нестабильности. Модифицированная классификация Meyers–McKeever остается наиболее широко применяемой рентгенологической системой, тогда как магнитно-резонансная томография предоставляет дополнительную информацию об ущемлении менисков, повреждении суставного хряща, сопутствующих повреждениях связочного аппарата и морфологии перелома. Переломы I типа обычно лечат консервативно; тактика при повреждениях II типа остается дискуссионной и требует оценки качества репозиции и наличия интерпозиции мягких тканей, тогда как полностью смещенные переломы III типа и многооскольчатые переломы IV типа, как правило, требуют хирургической фиксации. Артроскопическая репозиция и внутренняя фиксация обеспечивают прямую визуализацию зоны перелома и позволяют одновременно устранить сопутствующую внутрисуставную патологию.

Ключевые слова: передняя крестообразная связка, межмыщелковое возвышение большеберцовой кости, тибиальный гребень, отрывной перелом, МРТ, артроскопия, шовная фиксация, винтовая фиксация, нестабильность коленного сустава.

ОЛДИНГИ ХОЧСИМОН БОЙЛАМНИНГ ТИБИАЛ БИРИКИШ СОҲАСИДАГИ КАТТА БОЛДИР СУЯГИ ДЎМБОҚЧАЛАР ОРАСИ БАЛАНДЛИГИ УЗИЛИБ-СИНИШЛАРИДА ТАШХИС ВА ДАВОЛАШ ТАКТИКАСИ: ЗАМОНАВИЙ ШАРҲ

Аннотация. Катта болдир суяги дўмбоқчалар ораси баландлигининг узилиб-синишлари олдинги хочсимон бойламнинг тибиал бирикиш соҳасини қамраб олувчи бўғим ичи жароҳатлари бўлиб, айниқса болалар ва ўсмирларда кўп учрайди, аммо юқори энергияли жароҳатлардан кейин катталарда ҳам кузатилиши мумкин. Замонавий даволаш тактикаси суяк фрагментининг силжиш даражаси ва майдаланишини, юмшоқ тўқималар интерпозициясини, менисклар шикастланишини, беморнинг скелет етуклигини ва қолдиқ олдинги беқарорликни баҳолашни талаб этади. Meyers–McKeever модификацияланган таснифи ҳанузгача энг кўп қўлланиладиган рентгенологик тизим бўлиб қолмоқда, магнит-резонанс томография эса

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менискларнинг қисилиб қолиши, бўғим тоғайи шикастланиши, бойлам аппаратининг ҳамроҳ жароҳатлари ва синиқ морфологияси тўғрисида қўшимча маълумот беради. I турдаги синиқлар, одатда, консерватив даволанади; II турдаги жароҳатларда даволаш тактикаси ҳали ҳам баҳсли бўлиб, репозиция сифати ва юмшоқ тўқималар интерпозициясини баҳолаш талаб этилади. Тўлиқ силжиган III турдаги ва майдаланган IV турдаги синиқлар эса, одатда, жарроҳлик фиксациясини талаб қилади. Артроскопик репозиция ва ички фиксация синиқ соҳасини тўғридан-тўғри кўриш имконини беради ҳамда ҳамроҳ бўғим ичи патологиясини бир вақтнинг ўзида бартараф этишга шароит яратади.

Калит сўзлар: олдинги хочсимон бойлам, катта болдир суяги дўмбоқчалар ораси баландлиги, тибиал гребень, узилиб-синиш, МРТ, артроскопия, чокли фиксация, винтли фиксация, тизза бўғими беқарорлиги.

Relevance. Tibial eminence avulsion fractures are a specific form of anterior cruciate ligament injury in which the ACL remains attached to a bony fragment separated from the intercondylar eminence of the tibia. In skeletally immature patients, the incompletely ossified tibial insertion may fail before the ligament itself, explaining why this fracture pattern is more typical of children and adolescents than midsubstance ACL rupture. The reported incidence in children is approximately 3 per 100,000 per year, with the highest frequency between 8 and 14 years of age. Sports trauma, bicycle accidents, falls, sudden hyperextension, and rotational mechanisms are among the common causes.

The clinical importance of these fractures extends beyond bony union. The displaced fragment carries the tibial insertion of the ACL; therefore, incomplete reduction may alter ligament length and orientation even after fracture healing. Residual anterior laxity, loss of extension, arthrofibrosis, nonunion, and associated meniscal pathology may affect the final functional result.

Objective. To analyze contemporary concepts of diagnosis, classification, conservative management, and surgical treatment of tibial eminence avulsion fractures involving the tibial attachment of the anterior cruciate ligament.

Materials and Methods. An analytical literature review was performed with emphasis on contemporary systematic reviews, meta-analyses, clinical series, and technical studies addressing tibial eminence fractures. Particular attention was given to fracture classification, radiography, CT and MRI assessment, associated intra-articular injuries, indications for surgery, arthroscopic reduction, screw and suture fixation, complications, and recent all-suture and cortical suspensory techniques.

Results. Clinical examination frequently reveals acute knee pain, rapid joint swelling or hemarthrosis, inability to bear weight, restricted range of motion, and tenderness around the proximal tibia. Assessment of ACL stability immediately after trauma may be difficult because pain, muscle guarding, and hemarthrosis can limit Lachman and anterior drawer testing. A careful neurovascular examination remains necessary, particularly after high-energy mechanisms.

Conventional anteroposterior and lateral radiographs are the first imaging studies. The lateral view is especially important for evaluation of anterior elevation and rotation of the avulsed fragment.

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Small osteochondral fragments or complex fracture lines, however, may be underestimated on plain radiographs. CT is useful when the fragment is small, comminuted, extends into the tibial plateau, or requires detailed preoperative evaluation.

The modified Meyers–McKeever classification remains central to therapeutic decision-making. Type I fractures are nondisplaced or minimally displaced, generally less than 3 mm. Type II injuries demonstrate elevation of the anterior part of the fragment with preservation of a posterior bony hinge. Type III fractures are completely displaced and may be subclassified according to fragment rotation. Type IV, introduced by Zaricznyj, includes displaced comminuted fractures. More recent MRI-based systems attempt to quantify displacement and integrate associated soft-tissue pathology into classification.

MRI has an important role that differs from CT. CT describes osseous morphology more precisely, whereas MRI evaluates the ACL substance, menisci, articular cartilage, collateral and other cruciate ligaments, bone bruising, and soft tissues located beneath the avulsed fragment. A systematic review of 26 studies on skeletally immature patients reported meniscal tears in 18.1% and meniscal or intermeniscal ligament entrapment in 20.1% of tibial eminence fractures. These findings support active assessment for associated intra-articular pathology rather than treating the injury as an isolated bone fracture [1].

Soft-tissue interposition is particularly relevant in type II injuries. The anterior horn of the medial meniscus, lateral meniscus, or transverse intermeniscal ligament may become trapped beneath the elevated fragment and prevent satisfactory closed reduction. Consequently, persistent displacement after attempted reduction should not automatically be interpreted as simple mechanical instability of the bony fragment; an anatomical block may be present.

Nonoperative treatment remains accepted for type I injuries. Immobilization in a cast or brace is used after confirmation of acceptable alignment, followed by radiographic monitoring and progressive rehabilitation. The optimal position and duration of immobilization vary between protocols, but the general objective is to maintain reduction while avoiding prolonged stiffness.

Type II fractures represent the main therapeutic gray zone. Closed reduction may be attempted, particularly when displacement is limited and the posterior hinge remains intact. Persistent displacement, redisplacement during follow-up, soft-tissue entrapment, inability to restore full extension, or significant residual laxity shifts the decision toward surgical management. Contemporary reviews emphasize that the distinction between type I and type II may itself be difficult on plain radiographs and that MRI is particularly useful when conservative treatment is being considered.

Types III and IV usually require operative reduction because complete displacement or comminution makes stable anatomical healing without fixation less predictable. Historical open reduction remains an effective method, but arthroscopic reduction and internal fixation has increasingly become the preferred strategy because it combines minimally invasive access with direct visualization of the joint.

The main advantage of arthroscopy is not merely the smaller incision. Arthroscopy permits evacuation of hemarthrosis, assessment of the ACL substance, identification of meniscal or ligament

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entrapment, removal of interposed tissue, visualization of the entire fracture bed, controlled reduction, and simultaneous management of associated intra-articular injuries.

A 2024 systematic review and meta-analysis including 48 studies and 1,367 patients compared surgical approaches and fixation methods. Arthroscopic fixation produced better knee stability according to anterior drawer and Lachman testing than open fixation, although differences in Lysholm, IKDC, Tegner scores and return to sport were not significant. The same analysis found improved stability and several functional outcomes after suture fixation compared with screw fixation [2].

Screw fixation remains technically attractive because it provides direct compression across a sufficiently large bony fragment and may reduce operative time. The method is most suitable when the avulsed fragment is large, structurally intact, and capable of safely accepting a screw. Limitations include fragment splitting, prominence of intra-articular hardware, potential physeal injury in immature patients, and the possibility of later hardware removal.

Suture fixation distributes fixation forces over a larger ligament–bone complex and does not require insertion of a rigid implant through a small or fragmented bony piece. Sutures may be passed through the ACL near its tibial attachment, through the bony fragment, or around the ligament–fragment complex and subsequently secured through transtibial tunnels, anchors, or cortical fixation devices.

The 2025 meta-analysis by Manaf et al. included 9 studies and 412 patients. No significant differences were demonstrated between screw and suture fixation in Lysholm, Tegner, IKDC scores, range of motion, Lachman, pivot-shift, KT-1000 measurements, or fracture union time. Screw fixation, however, was associated with a substantially higher rate of subsequent surgery: 29.75% compared with 11.6% after suture fixation. Screw fixation also had more complications but required less operative time, approximately 67 versus 85 minutes [3].

Evidence in skeletally immature patients supports the same tendency. A pediatric meta-analysis involving 224 patients found that suture fixation was associated with lower reoperation rates (OR=0.22; 95% CI 0.12–0.42) and markedly lower hardware removal (OR=0.08), while postoperative instability, surgically treated arthrofibrosis, and recovery of full range of motion did not significantly differ between fixation methods [4].

The reduction in hardware removal is clinically relevant. A technically successful fixation should ideally not create the need for a second operation solely because of implant prominence or irritation. This consideration becomes particularly important in children and adolescents, where another anesthetic procedure and repeated intervention around the proximal tibial physis are undesirable.

Modern fixation technology continues to evolve beyond the conventional screw-versus-suture comparison. Re-tensionable all-suture constructs combine multiple looped stitches with cortical suspensory fixation, allowing the surgeon to restore tension after initial cyclic loading and to avoid placement of a large rigid implant within the avulsed fragment [5].

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Dual transtibial tunnel techniques provide another solution. Sutures passed through different areas of the ACL–fragment complex permit multidirectional compression and better control of fragment rotation. Cortical buttons on the anteromedial tibial cortex can maintain tension outside the joint and are particularly useful when the fragment is too small or comminuted for screw fixation [6].

The choice of fixation should therefore be based on fracture morphology rather than surgeon preference alone. A large single fragment in a skeletally mature patient may be appropriately treated with a screw. A thin, comminuted, or small fragment may be better suited to transosseous suture fixation. Physeal-sparing techniques deserve particular consideration in immature patients.

Complications remain clinically important regardless of fixation technique. Arthrofibrosis is among the most frequently reported problems after tibial eminence fracture treatment. Delayed surgery, prolonged immobilization, severe initial injury, and delayed restoration of knee motion have all been discussed as potential contributors. Stable fixation should therefore permit controlled early rehabilitation without loss of reduction.

Residual ACL laxity represents another specific problem. The ACL itself may undergo elongation at the time of injury, and perfect osseous union does not invariably guarantee normal ligament tension. Postoperative assessment should therefore include both radiographic union and functional stability using clinical examination and, when indicated, instrumented laxity measurements.

Associated meniscal injury must also be incorporated into the treatment algorithm. In a systematic review, meniscal tears were found in approximately one fifth of pediatric tibial eminence fractures, while entrapment of the meniscus or intermeniscal ligament was also common [1]. Arthroscopy has a particular advantage in such cases because diagnosis and treatment can be performed during the same procedure.

Age influences both mechanism and associated injury pattern. Pediatric injuries more commonly produce bony avulsion because the developing tibial eminence represents the structurally weaker component of the ACL complex. In adults, the same fracture pattern can result from greater-energy trauma and may be accompanied by additional ligamentous or meniscal injuries; MRI therefore becomes particularly useful for defining the full extent of the lesion.

The contemporary management concept is consequently shifting from a simple fracture-type algorithm toward individualized decision-making. Classification remains necessary, but displacement alone is insufficient. Fragment size, comminution, ACL integrity, meniscal entrapment, skeletal maturity, associated cartilage injury, ability to obtain closed reduction, and risk of postoperative stiffness all influence treatment.

Conclusion. Tibial eminence avulsion fractures should be regarded as combined osteoligamentous injuries rather than isolated fractures of the proximal tibia. Accurate treatment requires restoration of the bony anatomy and functional tension of the anterior cruciate ligament.

Plain radiography remains the first-line diagnostic method, CT improves characterization of complex osseous morphology, and MRI provides essential information regarding the ACL, menisci, cartilage, soft-tissue entrapment, and associated ligamentous injury. The need for MRI is especially

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strong when nonoperative management is contemplated or when associated intra-articular injury is suspected.

Type I fractures are generally suitable for conservative treatment. Type II injuries require individualized assessment of displacement and reducibility, whereas types III and IV usually require operative fixation. Arthroscopy offers direct control of reduction and enables simultaneous treatment of associated pathology.

Current comparative evidence demonstrates good functional results with both screws and sutures. Suture fixation has particular advantages in small or comminuted fragments and is associated with fewer hardware-related secondary procedures. New all-suture and cortical suspensory systems further support a transition toward stable, low-profile, and patient-specific fixation.

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