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# When meniscal injury is not just a sports injury – a literature review of mechanisms, risk factors, and management in high-performance athletes

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**Abstract:**

Introduction: This review paper aims to emphasize the critical role of the knee menisci in maintaining joint function and stability, highlight their vulnerability to injury in high-performance sports, and present an overview of current knowledge regarding risk factors, mechanisms of injury, diagnostic approaches, treatment options, complications, rehabilitation strategies, and return-to-sport (RTS) criteria. It seeks to demonstrate that accurate diagnosis and evidence-based management are essential for optimal outcomes, particularly in athletic populations, where early and safe return to play is a key objective.

Material and methods: This review includes approximately 35 scientific publications published between 2000 and 2025, sourced from databases such as PubMed, PMC, and orthopedic journals. The focus was on systematic reviews, meta-analyses, cohort studies, randomized trials, and precise clinical descriptions related to menisci in the context of sports. Selection was based on methodological quality and clinical relevance.

Summary: Meniscal injury is a significant condition that can lead to joint dysfunction, long-term complications, and impaired athletic performance if not properly diagnosed and managed. Accurate diagnosis is essential, as symptoms may be nonspecific and meniscal damage can vary in location, type, and severity. Prompt and appropriate treatment—including conservative or surgical interventions—combined with structured rehabilitation, plays a crucial role in restoring knee function and enabling a safe return to sport.

Conclusions: Lesser-known risk factors for meniscal injuries include biomechanical abnormalities, chronic overload, previous knee trauma, and coexisting joint disorders. It is important that when characteristic symptoms such as pain, swelling, or limited range of motion occur, thorough diagnostic evaluation and appropriate treatment and rehabilitation are implemented. An individualized patient approach, which considers both prevention and effective therapeutic management, is crucial for full recovery and safe return to sports activity.

Key words: meniscus injury, meniscal repair, diagnosis of meniscal injury, return to sport

## Introduction

The knee menisci are critical components of the knee joint, performing essential biomechanical, stabilizing, sensory, and nutritional roles. These structures develop from mesenchymal tissue during the embryonic period between the eighth and tenth week of gestation. As development progresses, they transform from highly vascularized, cell-rich primordia into structures with limited vascularization, which in adulthood is confined to just 10–30% of the outer width of the meniscus. The menisci are crescent-shaped—the medial meniscus resembles the letter "C", while the lateral meniscus is more circular and covers a larger area of the tibial plateau.[1] In cross-section, they appear triangular and occupy between half and two-thirds of the tibial articular surface. The anterior and posterior horns of each meniscus are firmly anchored to the tibia by root ligaments, and the menisci are also connected anteriorly via the transverse ligament. The meniscofemoral ligaments play an important role in stabilizing the posterior horn of the lateral meniscus.[2]

In terms of tissue composition, type I collagen fibers predominate in the meniscus (accounting for up to 90% of its dry weight), supported by proteoglycans, glycoproteins, and fibroblast-like cells. The fiber orientation—primarily circumferential and radial—enables the transmission of loads via so-called hoop stresses, which allow for the distribution of compressive forces within the joint. The central layers of the meniscus contain less fibrous tissue and are more hydrophilic, further supporting shock absorption and stabilization.

Meniscal vascularization primarily involves the outer portions—the so-called red zone—which receives blood supply from synovial vessels (mainly from the inferior branches of the popliteal artery). The inner portion—the white zone—is avascular and sustained by diffusion from synovial fluid, which limits its natural healing capacity. Vascularization diminishes with age-in adults, it reaches only 10–30% of the meniscus width.[1]

Menisci serve several key biomechanical functions. Primarily, they enhance congruence between the convex surfaces of the femur and the relatively flat tibial plateau, which increases contact area and reduces focal cartilage stress.[2] It is estimated that during knee extension, the menisci transmit about 50% of the load, and during flexion, up to 85% of the load passing through the joint. Due to their elasticity and fiber structure, menisci absorb shocks and stabilize the joint—the medial meniscus, in particular, acts as a secondary stabilizer against anterior tibial translation, especially in the context of anterior cruciate ligament (ACL) instability.[1]

Beyond mechanics, the menisci contribute to the production, distribution, and lubrication of synovial fluid, reducing friction and preventing cartilage degeneration. They also support joint proprioception via nerve endings located in the meniscal horns, which assist in stabilizing reflexes during movement.[2]

From a surgical standpoint, detailed knowledge of meniscal root and attachment anatomy is essential, especially when planning anatomical repairs or reconstructions following injury. Increasing attention is being given to restoring the original position and tension of the meniscus, which leads to improved joint function and slows cartilage degeneration.[3]

In summary, the anatomical structure of the menisci—from their shape and attachments to the ultrastructure of collagen fibers and vascularized zones—enables them to fulfill their roles in force transmission, load absorption, joint stabilization, and support of sensory and nutritional mechanisms. Understanding these elements forms the foundation for interpreting injury mechanisms, treatment approaches, and surgical decisions regarding meniscus preservation or reconstruction to maintain long-term knee joint health.[4]

## Types of Meniscal Injuries

Meniscus injuries are among the most common pathologies of the knee joint, especially in the context of anterior cruciate ligament (ACL) injuries. Disruptions to meniscal structure affect not only knee biomechanics but also significantly influence therapeutic approaches and prognosis. Reports indicate that among patients undergoing ACL reconstruction, the incidence of concurrent meniscus injuries is as high as 44.4%, highlighting their clinical importance.[2]

In one retrospective study involving over a thousand ACL reconstruction procedures, five dominant types of meniscus injuries were identified. The most common was the bucket-handle tear, accounting for approximately 30% of all cases. This type of injury involves the detachment of a meniscal fragment in such a way that it forms a "bucket handle" shape, which can lead to mechanical locking of the knee. Another frequently observed type was the radial tear (27%), which disrupts the radial fiber alignment, thereby destabilizing hoop stresses and impairing load transmission. This type is particularly challenging to treat, especially when the tear extends into the avascular zone. The flap tear ranked third in frequency (23.2%) and involves partial detachment of a meniscal fragment, often causing mechanical symptoms such as clicking or pain. Less common were longitudinal tears (12.8%)—tears along the length of the meniscus, potentially repairable in vascularized zones—and horizontal tears (6.6%), typically degenerative in nature and more often seen in older individuals.[2][5]

The distribution of tear types varied depending on the chronicity of the ACL injury. In acute cases, lateral meniscus injuries were more common, whereas chronic injuries more frequently involved the medial meniscus. A significant difference was also noted in the incidence of radial tears, which were far more common in patients with acute ACL injuries compared to chronic ones. The same study also reported the occurrence of ramp lesions and root tears as clinically significant types. Ramp lesions, involving injuries to the meniscocapsular and meniscopopliteal attachments, were found in approximately 9% of all patients—more commonly in those with chronic ACL injuries. Type I ramp lesions were the most prevalent, followed by types V and IV. Root tears, affecting the meniscal roots, were less frequent (around 3% of meniscal injuries) but biomechanically significant, as they can severely compromise joint function—mimicking the effect of a subtotal meniscectomy. Root tears were also found to be significantly more common in patients with acute ACL ruptures.[5,6,7]

Another study proposed a narrative classification of meniscal tear types based on their biomechanical impact, treatment difficulty, and prognosis. This classification divides injuries into three categories: “Good,” “Bad,” and “Ugly.” The "Good" group includes stable injuries with minimal impact on knee function, good prognosis, and relatively easy repair. The "Bad" group includes injuries that significantly disrupt biomechanics—such as ramp lesions—but may have good outcomes if diagnosed and treated early. The "Ugly" group includes the most severe tears, such as root tears, extensive radial tears, and bucket-handle tears. These are

difficult to treat and carry a high risk of poor functional outcomes even with surgical intervention.

According to one study, more than half of the injured menisci (56.6%) underwent repair, while the remainder required partial meniscectomy. The choice of treatment method depended primarily on the type of injury and its location relative to the vascular zones. In this context, the "Good, Bad, Ugly" classification can be a useful tool to support prognosis and therapeutic decision-making, complementing traditional classification systems.[8]

In summary, understanding the types of meniscus injuries, their frequency, and their functional significance is crucial for proper treatment planning—especially in cases involving concurrent ACL injuries. This knowledge directly affects surgical outcomes and the potential to preserve meniscal structure.[2,8]

**Risk factors and injury mechanisms in elite athletes**

Risk factors for meniscus injury and the mechanisms behind such injuries in elite athletes are multifactorial, involving both the nature of physical activity and individual predispositions. Among the most significant risk factors is participation in sports such as soccer, rugby, basketball, volleyball, and wrestling—disciplines characterized by dynamic movements involving sudden knee twisting and contact with opponents.[9] One study highlighted that the risk of meniscus injury is particularly high in rugby and soccer players, with a notably higher frequency of both overuse and contact-related injuries. Among Olympic-level and elite athletes, the knee has been identified as the second most commonly injured body part during the Summer and Winter Olympic Games, as well as Youth Olympics, with the majority of cases occurring in sports such as soccer.[10]

The injury mechanism in elite athletes most often involves a sudden twist of the knee while the foot is planted, frequently accompanied by contact with another player. In high-level sports, movements such as pivoting—changing direction with the foot fixed on the ground—generate high mechanical loads on the joint. Data show that pivoting is the most common injury mechanism in football, baseball, and softball, while jumping and landing are more frequent causes in volleyball and basketball. In contact sports, injuries resulting from physical contact account for approximately 42% of cases, whereas non-contact injuries account for about 38%, with women being more likely to sustain the latter.[11,12]

All of these factors, when combined with an anterior cruciate ligament (ACL) injury, significantly increase the risk of meniscal damage. Among young athletes (average age ~25 years), the coexistence of ACL and meniscus injuries occurs in 16% to 82% of acute ACL injuries and in up to 96% of chronic ACL insufficiencies. The time interval between ACL injury and surgical reconstruction is also important—the longer the delay, the higher the likelihood of meniscal damage.[13]

Other general risk factors include being overweight, generalized joint hypermobility, and occupational or daily activities involving frequent kneeling, squatting, or stair climbing. While these factors are more commonly associated with the non-athletic population, they suggest similar overload mechanisms that can affect meniscal integrity.

In elite athletes, the specific loading patterns of the knee joint and the intensity of training also influence the likelihood of injury and the ability to return to full function. Although not all studies focus specifically on athletes, analyses show that athletes aiming for a rapid return to professional-level performance may face adverse outcomes if they opt for a meniscectomy instead of meniscus repair—particularly in sports requiring axial loading and rotational movements.[14]

**Diagnosis**

The diagnosis of meniscal injuries in elite athletes requires a detailed clinical and imaging-based approach, taking into account factors specific to this population. The first step involves a thorough patient history and physical examination, which may already suggest a meniscal injury. Common symptoms include joint line pain, swelling, reduced range of motion, locking, or catching of the knee.[15] The most frequently used clinical tests are McMurray's test and the Thessaly test, which—despite differing in sensitivity and specificity—can indicate meniscal pathology if positive. Additionally, Apley's test or Ege's test are sometimes used to complement the mechanical assessment of the joint.

Physical examination alone usually does not allow for a definitive diagnosis. For athletes who require precise evaluation prior to treatment, imaging diagnostics become essential.[16] The gold standard is magnetic resonance imaging (MRI), which allows for a detailed assessment of the type and location of the injury as well as associated abnormalities. Literature emphasizes that MRI provides high sensitivity and diagnostic accuracy, which further improves when paired with positive clinical test results.[17] In relation to elite athletes, some studies indicate that advanced deep learning algorithms, such as the Mask R-CNN network with ResNet50, can significantly improve the precision of automatic meniscal tear detection on MRI scans—with reported accuracy for identifying degenerative and traumatic tears reaching 86–88%.[18]

In a few highly specialized medical centers, joint ultrasound is also considered in the diagnosis of meniscal injuries in professional athletes. Although this method does not replace MRI, it is quick, may be available in-office, and offers insight into the medial meniscus attachments—including regions typically difficult to assess by other means. In elite sports medicine, early diagnosis and determination of conservative versus surgical treatment options are especially important.[19]

In cases of suspected bucket-handle tears, clinical symptoms—especially knee locking and a positive McMurray's test—combined with a characteristic MRI finding (the "double PCL sign") support the diagnosis of a displaced meniscal fragment. This type of injury, particularly in athletes requiring full joint mobility, often necessitates surgical repair, as leaving the fragment may significantly impair joint function.[20]

Differentiating between traumatic and degenerative meniscus injuries is crucial in young and active athletes. Traumatic tears often present as clear fiber disruptions on MRI, whereas degenerative changes appear as more irregular, horizontal clefts. In athletic populations, clinical image interpretation should always consider the patient's age, injury history, and type of joint loading.[21]

In diagnostically challenging cases—such as suspected root injuries or meniscal instability with inconclusive MRI results—diagnostic arthroscopy may be considered. This technique allows for direct visualization of intra-articular structures and simultaneous treatment, which is particularly important in elite athletes where optimal timing of return to play often guides treatment decisions.[22]

Functional assessment of the knee joint after diagnosis, regardless of the treatment method, includes performance tests, range of motion evaluation, muscle strength, and stability assessments. These tests are useful both preoperatively and during monitoring of return to sport—especially after meniscal repair, which typically requires a longer rehabilitation period than meniscectomy.[23]

**Treatment**

The treatment of meniscus injuries in athletes—particularly at the elite level—must balance the demands for a quick return to activity with the long-term protection of the knee joint. In cases where surgical repair is possible, the priority is to preserve meniscal tissue, allowing restoration of its function, reducing the risk of degeneration, and supporting joint stability over time. Research indicates that after isolated meniscal repairs, approximately 83% of athletes return to play.[24] Although some athletes opt for partial meniscectomy, especially when the injury is difficult to repair, data suggests this approach enables a faster return (on average 1.5–2 months), but it may also carry a higher risk of complications such as chondrolysis, particularly with lateral meniscus injuries.[25]

When anatomical repair of the meniscus is feasible, even in lateral injuries, suture repair is clearly preferred. This allows for the restoration of the natural shape, favorable healing potential, and high success rates in returning to pre-injury performance levels. Despite a longer rehabilitation period (typically 4–6 months), return-to-sport and functional outcomes are comparable to those after meniscectomy. However, there is a higher revision rate—approximately 20% of patients required additional intervention, usually partial meniscectomy.[26]

Rehabilitation following meniscal repair is crucial and has recently shifted toward an accelerated recovery model. Although there is no universal protocol, early loading and unrestricted range of motion are increasingly implemented, especially in stable tears. Biomechanical studies using comparative models suggest that flexion up to 90° and early mobilization do not adversely affect suture integrity, supporting faster mobilization without increasing the risk of repair failure.[27]

Despite significant advances, an individualized approach is necessary. Factors such as tear type (e.g., radial or root tears), location (medial vs. lateral), concomitant injuries like ACL rupture, and the timeline for return to competition influence treatment selection. In many cases, conservative treatment is recommended for degenerative tears in vascular zones, while surgical repair is preferred in acute bucket-handle or root tears—especially in younger athletes.[25]

When repair is not possible, partial meniscectomy may be performed to enable a quicker return to sport. This strategy often allows return within 7 to 9 weeks, under strict supervision and structured rehabilitation. In contact sports and disciplines requiring pivoting, the knee joint is subjected to high stresses, so treatment must balance rapid return with long-term joint durability.[26]

In cases where standard treatments fail or the meniscal structure is irreparably damaged, allograft transplantation may be considered. Although still relatively rare, this procedure offers hope for athletes with large tissue deficits, enabling joint function to be preserved even over the course of several years.[28]

Final assessment of treatment success should include not only short-term outcomes but also joint function, activity levels, patient satisfaction, and structural imaging. Increasingly, combined outcome measures—revision rates, clinical results, and patient-reported outcomes (PROMs)—are being used to provide a comprehensive picture of treatment efficacy.[29]

In conclusion, the treatment of meniscal injuries in elite athletes prioritizes repair whenever feasible, with a cautious rehabilitation schedule tailored to injury type and stability. In cases not amenable to reconstruction, limited meniscectomy may be used to enable a prompt return to competition. Osteoarthritis remains a significant long-term concern, thus emphasizing the importance of tissue preservation to ensure lasting joint function.

## Rehabilitation and prevention

Rehabilitation following meniscal injury in elite athletes integrates structured phase-based protocols with preventive strategies aimed at optimizing return to sport and reducing the risk of reinjury. The early phase focuses on pain and swelling management, while protecting the surgical repair. Depending on the injury type and stability, the protocol may include early partial weight-bearing (e.g., up to 20 kg) with flexion restricted to 90° for the first four weeks, or—if the injury is unstable (e.g., radial or root tears)—complete offloading for about six weeks. This approach reduces stress on the repair and creates favorable healing conditions.[30]

In the following weeks, therapy focuses on gradually increasing load and range of motion, progressing to full weight-bearing as tolerated, and introducing isometric exercises, quadriceps activation, and core stability training. Once adequate muscular control is achieved, a functional phase begins—emphasizing balance drills, single- and multi-plane load-bearing exercises, and proprioceptive training, including on uneven surfaces, which enhances reactive capabilities under dynamic conditions.[31]

In later stages, focus shifts to sport-specific training: plyometrics, multidirectional landing drills, and explosive strength work. Functional tests—such as single-leg strength assessment, balance testing, range of motion measurements, and validated functional self-assessment questionnaires (e.g., IKDC, KOOS)—form the basis of return-to-sport decisions. These decisions should never be based on time alone, but rather on test performance and the absence of clinical symptoms.[32]

As for return-to-sport rates, they reach 83–90% after meniscal repair in athletes, although lateral repairs may carry a higher reoperation rate (approximately 17%). Athletes typically return to training more quickly after partial meniscectomy—often within 7 to 8 weeks—but the rehabilitation period is shorter at the cost of increased long-term risk of degeneration.[33]

The principle of "too early return" is particularly relevant for young athletes, as it may lead to treatment failure. Therefore, in unstable tears such as radial or root lesions, return to sport is generally postponed for up to nine months post-surgery. In more stable injuries, return at four to six months may be safe—provided functional criteria are met.[30]

Meniscal injury prevention in elite athletes is primarily based on neuromuscular and proprioceptive programs, which reduce the risk of knee injuries, particularly in sports involving frequent twisting and contact. These programs include balance training on unstable surfaces, strengthening of thigh, calf, and gluteal muscles, and instruction in proper landing techniques and direction changes. Their effectiveness in reducing ACL injuries has been well documented, indirectly protecting the meniscus as well.[34]

Additionally, athlete education plays a key role—especially in avoiding overload due to high training loads—and includes monitoring joint health via assessments of body mass, muscle balance, joint mobility, and musculoskeletal adaptation. Proper nutrition, recovery, and limiting repetitive high-load movements are essential components of comprehensive prevention.[35]

## Conclusion

This review demonstrates that meniscal injuries are a significant issue in elite sports. Accurate assessment of tear type, vascularization, and location is critical in selecting optimal treatment. Meniscal repair is preferred due to its superior functional outcomes and reduced risk of osteoarthritis. Return to sport requires a comprehensive therapeutic and rehabilitation approach, along with evaluation of the athlete's psychological readiness and biomechanical competence.

## Disclosure

**Author's contribution**

**Conceptualization:** Michał Bursztyn,

**Methodology:** Michał Bursztyn, Tomasz Bursztyn,

**Formal analysis:**

**Investigation:**

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