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Anterior Cruciate Ligament Injuries in Athletes: Risk Factors, Mechanisms, Treatment, and Return-to-Sport Outcomes – A Narrative Review

Krzysztof Bednarski
Beskid Oncology Center Municipal Hospital of John Paul II, Bielsko-Biała, Poland
drkrzysztofbednarski@gmail.com
https://orcid.org/0009-0000-9801-2832

Natalia Kornacka
Beskid Oncology Center Municipal Hospital of John Paul II, Bielsko-Biała, Poland
leknataliakornacka@gmail.com
https://orcid.org/0009-0003-3657-2027

Melania Majewska
County Medical Center in Grójec, Poland
melania.majewska23@gmail.com
https://orcid.org/0009-0009-5334-6965

Natalia Piasecka
University Clinical Center of the Medical University of Warsaw, Poland
natalia.piasecka1810@gmail.com
https://orcid.org/0009-0001-2361-8060

Izabela Rafalska
Upper Silesian Medical Centre of Prof. Leszek Giec, Medical University of Silesia, Katowice, Poland
iza.rafalska@op.pl
https://orcid.org/0009-0003-1687-8037

Jakub Smagoń
Upper Silesian Medical Centre of Prof. Leszek Giec, Medical University of Silesia, Katowice, Poland
jakubsmagon@gmail.com
https://orcid.org/0009-0008-0109-7349

Martyna Kaim
District Hospital in Limanowa, Poland
martyna.kaim@onet.eu
https://orcid.org/0009-0001-6818-6732

Joanna Bober
Provincial Specialist Hospital in Wroclaw, Poland
joannabober09@gmail.com
https://orcid.org/0009-0007-0118-885X

Magdalena Bochenek
Provincial Specialist Hospital in Wroclaw, Poland
magdabochenek03@gmail.com
https://orcid.org/0009-0006-3997-2810

Wiktoria Siewiera
American Heart of Poland: Ustroń, Silesia, Poland
wsiewiera6@gmail.com
https://orcid.org/0009-0009-1875-0209

Corresponding Author
Krzysztof Bednarski, drkrzysztofbednarski@gmail.com

Abstract:

Background: Anterior cruciate ligament (ACL) injury is a common and serious injury in athletes, particularly in sports involving pivoting, jumping, and rapid direction changes. ACL rupture may result in knee instability, reduced performance, prolonged absence from sport, and increased risk of osteoarthritis.

Aim: The aim of this study was to summarize current evidence regarding risk factors, treatment, rehabilitation, and return-to-sport outcomes after ACL injury in athletes.

Materials and methods: This narrative review analyzed current literature on ACL injuries in athletes. Studies concerning epidemiology, injury mechanisms, treatment strategies, rehabilitation, and return to sport were identified using PubMed, Scopus, and Google Scholar. English-language publications from 2000–2024 were included.

Results: ACL injury is multifactorial and strongly associated with neuromuscular and biomechanical deficits. Prevention programs focused on neuromuscular training may reduce injury risk. ACL reconstruction combined with structured rehabilitation remains the preferred treatment for many athletes. Criteria-based return-to-sport assessment is increasingly recommended to reduce re-injury risk.

Conclusions: Effective ACL injury management requires prevention, individualized rehabilitation, and evidence-based return-to-sport decisions. Despite advances in treatment, the risk of secondary injury remains significant.

KEYWORDS: anterior cruciate ligament; ACL injury; athletes; risk factors; rehabilitation; return to sport

1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most common and most disabling musculoskeletal injuries seen in athletes [1,2]. It occurs particularly often in sports that involve sudden deceleration, rapid changes of direction, pivoting, and jumping, such as football, basketball, handball, and skiing [2,3]. Over the past few decades, the incidence of ACL injury has increased, especially among young and physically active people, which has made it a major issue in both sports medicine and orthopedic practice [4].

For many athletes, ACL rupture is much more than just a temporary break from training or competition. It often leads to joint instability, reduced performance, and a long period away from sport [5]. Its consequences may also go far beyond the acute phase. Meniscal injury and cartilage damage often occur together with ACL tears, and these associated lesions may accelerate degenerative changes in the knee and increase the risk of post-traumatic osteoarthritis [6,7]. For this reason, ACL injury should be seen not only as a cause of short-term disability, but also as a condition that may have lasting consequences for joint health and quality of life.

The etiology of ACL injury is generally considered to be multifactorial [8]. A number of intrinsic factors may contribute to susceptibility, including anatomical features, neuromuscular control deficits, hormonal influences, and genetic predisposition [9]. Sex-related differences have also been described consistently, with female athletes showing a higher injury risk than males participating in similar sports [10]. At the same time, extrinsic factors such as the type of sport, level of competition, playing surface, footwear, and environmental conditions also influence overall risk [3].

One of the most important findings in ACL research is that most ruptures happen without direct contact [11]. This has shifted attention toward modifiable contributors such as poor landing mechanics, dynamic knee valgus, limited knee flexion, and insufficient muscular stabilization around the knee and trunk [12]. From a prevention point of view, this is particularly important, because many of these deficits can be addressed through properly designed training interventions.

Although treatment of ACL injury has developed significantly, it still remains a topic of discussion [13]. Conservative management may be suitable for selected patients, but reconstruction is generally recommended for athletes who want to return to pivoting or other high-demand sports [14]. Even so, surgery itself does not determine the final outcome. The quality of rehabilitation, adherence to treatment, and the timing and criteria used for return to sport are equally important.

Return to sport (RTS) is one of the most meaningful outcomes after ACL injury, but also one of the most difficult to define and manage [15]. Not all athletes return to sport at their previous level, and even those who do remain at considerable risk of another injury [16]. As a result, more emphasis is now being placed on evidence-based, criteria-driven RTS decisions rather than on time since surgery alone.

The aim of this narrative review was to summarize current evidence concerning the risk factors, mechanisms, treatment options, and return-to-sport outcomes associated with ACL injuries in athletes.

2. Methods

This narrative review was undertaken to summarize current knowledge regarding ACL injuries in athletic populations, with particular attention to risk factors, injury mechanisms, treatment strategies, rehabilitation, and return-to-sport outcomes.

A literature search was conducted using three electronic databases: PubMed, Scopus, and Google Scholar. Both Medical Subject Headings (MeSH) and free-text terms were applied, including "anterior cruciate ligament", "ACL injury", "athletes", "risk factors", "mechanisms", "treatment", "rehabilitation", and "return to sport". Boolean operators such as "AND" and "OR" were used to improve the precision and relevance of the search.

Only English-language studies published between 2000 and 2024 were considered. Greater emphasis was placed on more recent publications to reflect current evidence, although earlier landmark studies were also included where they remain relevant to the topic. Eligible studies included original research articles, systematic reviews, and meta-analyses focusing on ACL injuries in athletic populations. Studies addressing epidemiology, biomechanics, injury mechanisms, treatment, rehabilitation, and return-to-sport outcomes were considered relevant for inclusion [2,5,14]. Studies involving non-athletic populations, case reports, editorials, conference abstracts without full-text access, and publications of limited relevance were excluded.

Study selection was based on screening titles and abstracts, followed by full-text assessment of potentially relevant articles. Due to the narrative nature of this review, no formal assessment of methodological quality or risk of bias was performed. Instead, priority was given to studies with higher levels of evidence, including randomized controlled trials, prospective cohort studies, and systematic reviews [13].

Because of the heterogeneity of the included studies in terms of design, populations, interventions, and outcome measures, no quantitative synthesis or meta-analysis was undertaken. The findings were therefore analyzed qualitatively and organized into thematic sections covering risk factors, injury mechanisms, treatment, and return-to-sport considerations.

This approach allowed for a broad and clinically relevant overview of the topic while maintaining the flexibility characteristic of narrative reviews.

3. Risk Factors for ACL Injury

ACL injury is best understood as the result of multiple interacting influences rather than one single causative event. In many athletes, rupture occurs when several predisposing factors are present at the same time, creating circumstances in which the ligament becomes vulnerable during high-demand sport-specific movements. These influences are commonly divided into intrinsic and extrinsic factors, although in practice the distinction is often blurred because both categories interact closely.

3.1. Intrinsic risk factors

Intrinsic factors relate to characteristics of the athlete and may include anatomical, biomechanical, neuromuscular, hormonal, and genetic influences.

Structural and anatomical factors

Several anatomical characteristics have been associated with an increased risk of ACL rupture. Among the most frequently discussed are a narrower intercondylar notch, a steeper posterior tibial slope, and smaller ACL dimensions [17,18]. These structural features may alter the way forces are transmitted across the knee during cutting, landing, and deceleration, thereby increasing strain on the ligament during dynamic loading.

Other anatomical variables, including an increased quadriceps angle and generalized joint laxity, have also been linked to greater susceptibility, particularly in female athletes [8,10]. Although such factors cannot be modified, they may help identify individuals at increased risk and justify a stronger focus on prevention.

Neuromuscular and biomechanical factors

Among the many contributors to ACL injury, neuromuscular control is particularly important because it is clinically relevant and, at least in part, modifiable. Dynamic knee stability depends on effective coordination between muscle groups, appropriate timing of muscle activation, and the ability to maintain alignment under load. When these mechanisms are impaired, the ACL may be exposed to excessive stress.

Reduced hamstring strength, delayed muscle activation, quadriceps dominance, and impaired proprioception have all been associated with increased anterior tibial translation and greater ACL loading [12,19]. Athletes who later sustain ACL injury often demonstrate movement patterns such as dynamic knee valgus, reduced knee flexion during landing, poor trunk control, and limited hip stability [20].

These deficits are important not only because they contribute to the initial injury mechanism, but also because they may persist after treatment and rehabilitation, thereby increasing the risk of subsequent injury.

Sex-related and hormonal influences

Differences in ACL injury rates between male and female athletes are well documented. Female athletes have consistently been shown to sustain ACL injuries more often than male athletes participating in similar sports [10]. This difference is likely multifactorial and probably reflects the combined effects of anatomical, hormonal, biomechanical, and neuromuscular influences rather than one single explanation.

Hormonal factors have received a great deal of attention, especially fluctuations in estrogen across the menstrual cycle. These changes may influence ligament laxity, collagen metabolism, and neuromuscular control [21]. Although the exact mechanisms are still not fully understood, hormonal influences continue to be considered a potentially important part of ACL injury risk in female athletes.

Genetic factors

In recent years, increasing interest has focused on genetic predisposition. Variants in genes related to collagen synthesis, extracellular matrix composition, and connective tissue structure may influence ligament strength and mechanical behavior [22]. At present, this area remains largely investigational, but in the future it may contribute to more individualized risk assessment.

3.2. Extrinsic risk factors

Extrinsic factors are environmental or sport-related influences that may either increase or reduce injury risk depending on the circumstances.

Sport-specific demands

The type of sport is one of the clearest determinants of ACL injury risk. Sports involving cutting, pivoting, repeated jumping, and sudden deceleration place particularly high demands on the knee and are consistently associated with elevated ACL injury rates. Football, basketball, handball, and skiing are among the most commonly cited examples [2,3]. Risk may also vary depending on the level of competition. Athletes competing at higher levels are usually exposed to greater speed, match intensity, training volume, and physical demands, all of which may create a more hazardous loading environment.

Playing surface and footwear

The interaction between footwear and playing surface is another factor that may influence knee biomechanics. High-friction surfaces may limit foot rotation and increase torsional forces transmitted to the knee [23]. Surface stiffness and traction can also affect movement mechanics and may either increase or reduce risk depending on the sport and playing conditions.

Fatigue and training load

Fatigue is increasingly recognized as a relevant contributor to ACL injury. As fatigue develops, movement quality may deteriorate, muscular responses may slow, and joint stability may decline [24]. Under these conditions, athletes may land with less flexion, demonstrate greater valgus collapse, and lose control of the trunk and hip. Excessive training load, inadequate recovery, and poor workload management may therefore increase injury risk indirectly by impairing neuromuscular control and reducing movement efficiency.

Modifiable and non-modifiable factors

From a practical perspective, ACL risk factors can be divided into modifiable and non-modifiable categories. Anatomical structure, sex, and genetic predisposition are essentially non-modifiable. In contrast, neuromuscular deficits, strength imbalances, and movement errors can be addressed through well-designed prevention and training programs [11,19]. This distinction is highly relevant in applied sports medicine. Neuromuscular training programs aimed at improving balance, coordination, strength, landing mechanics, and lower limb control have been shown to reduce ACL injury incidence, particularly in athletes considered to be at higher risk [8,12].

Overall, ACL injury risk should be seen as the product of multiple interacting influences rather than a simple one-cause phenomenon. This perspective supports the need for individualized risk assessment and multifaceted prevention strategies.

4. Mechanisms of ACL Injury

Most ACL injuries occur through non-contact mechanisms, accounting for approximately 70–80% of cases [11,20]. In practical terms, this means that rupture often occurs not because of a direct blow to the knee, but during sport-specific actions such as sudden deceleration, cutting, pivoting, or landing from a jump. This observation has been fundamental to modern prevention strategies, as it suggests that many injuries arise from modifiable movement patterns rather than from unavoidable trauma.

Biomechanical loading patterns

ACL rupture typically results from multiplanar loading of the knee. High-risk movements usually involve a combination of sagittal, frontal, and transverse plane forces. Commonly described features include dynamic knee valgus, limited knee and hip flexion, internal tibial rotation, and strong quadriceps activation without sufficient hamstring co-contraction. Dynamic knee valgus, often described as medial collapse of the knee, is one of the biomechanical patterns most frequently associated with ACL rupture. When combined with rotational stress and reduced flexion, this position substantially increases strain on the ligament. At the same time, a relatively extended knee is less capable of dissipating external forces effectively, which shifts greater load onto passive stabilizers such as the ACL. Quadriceps-dominant activation patterns may further increase injury risk by promoting anterior tibial translation. When hamstring activity is insufficient, the normal protective balance around the knee is reduced and ligament strain increases.

Kinematic and kinetic features

Video analyses have provided valuable insight into the real-life circumstances of ACL injury. In many cases, the athlete is seen planting the foot or landing with the trunk relatively upright, the knee insufficiently flexed, and the lower limb poorly aligned [20]. This is often followed by rapid valgus collapse, loss of postural control, and excessive load transfer through the knee. Trunk position appears to be especially important. Lateral displacement of the trunk may shift the center of mass beyond the base of support and thereby increase loading at the knee. Similarly, poor control of the hip and core may alter force transmission along the lower limb, making the knee more vulnerable during high-speed maneuvers. From a kinetic perspective, high ground reaction forces combined with ineffective force absorption strategies may further increase ligament stress. These findings highlight that ACL injury mechanisms involve the entire kinetic chain, not just the knee joint in isolation.

Neuromuscular control

Neuromuscular control is central to the injury mechanism. Appropriate muscle timing and coordination are essential for maintaining alignment and stabilizing the knee during demanding actions. When activation is delayed or muscular support is inadequate, control of knee position may be lost at a critical moment.

Insufficient hamstring activation relative to quadriceps contraction is particularly relevant because it increases anterior shear forces acting on the tibia. In addition, deficient trunk and hip control may contribute to movement strategies that place the knee in a more hazardous position.

This has major preventive significance, because such deficits are at least partly modifiable through training.

Role of fatigue

Fatigue may further amplify injury risk. As athletes become fatigued, they often land with less knee and hip flexion, show greater dynamic valgus, and respond more slowly to sudden changes in balance or direction [24]. Under these circumstances, the ability to absorb force and maintain joint stability is compromised, which increases the likelihood of ACL rupture.

The effects of cumulative fatigue related to congested competition schedules, high training loads, and inadequate recovery should not be underestimated.

Contact and indirect contact injury

Although non-contact injuries predominate, ACL rupture may also occur in contact situations. A direct blow to the knee may force it into valgus or rotational stress, while indirect contact may disturb body control and trigger an injurious movement pattern.

Even in these circumstances, however, underlying neuromuscular and biomechanical deficits may influence how the athlete responds to external force. This suggests that intrinsic and extrinsic factors remain relevant even when contact is involved.

Implications for prevention

The predominance of non-contact injury has major practical implications. It indicates that at least part of the ACL injury burden may be reduced through interventions aimed at improving movement quality, neuromuscular control, strength, landing technique, and trunk stability [8,12].

For this reason, prevention programs should not focus only on the knee. They should also target hip control, trunk function, whole-body coordination, and sport-specific motor patterns.

Taken together, current evidence suggests that ACL injury usually develops from a combination of unfavorable biomechanics and insufficient neuromuscular control during high-demand movements. Understanding these mechanisms is fundamental for both prevention and rehabilitation.

5. Treatment of ACL Injuries

The management of ACL injury in athletes remains complex and should always be individualized. The optimal approach depends on several factors, including age, level of sport participation, degree of instability, associated injuries, and expectations regarding future activity. In broad terms, treatment options can be divided into conservative and surgical management, although in practice both approaches require careful rehabilitation planning and thoughtful return-to-sport decision-making.

Non-operative treatment

Conservative treatment may be appropriate in selected patients, particularly those with partial tears, minimal instability, or lower functional demands. It may also be considered in individuals willing to modify their sports participation or avoid high-risk cutting and pivoting activities.

Structured rehabilitation is the cornerstone of non-operative management. Its main goals are to restore range of motion, improve muscle strength, enhance proprioception, and optimize dynamic knee control [25]. Particular attention is generally paid to quadriceps and hamstring strength, postural stability, and safe movement strategies during functional tasks.

A subgroup of patients may function well without reconstruction. These individuals are often referred to as “copers”, meaning that they can compensate for the absence of mechanical ligament stability through effective neuromuscular adaptation [26]. Among competitive athletes, however, such cases seem to be relatively uncommon.

In young and physically active individuals, non-operative treatment is often associated with a greater risk of recurrent instability and secondary intra-articular injury, especially involving the menisci and articular cartilage [6,13]. For this reason, conservative treatment is usually not the preferred strategy in athletes who aim to return to high-demand sport.

Surgical treatment

ACL reconstruction remains the standard treatment option for many athletes, particularly those intending to resume pivoting or high-level sports [14]. The main goals of surgery are to restore mechanical stability, reduce the risk of further joint damage, and create conditions for progression through rehabilitation toward safe return to sport.

Graft selection

Graft choice is an important aspect of ACL reconstruction. The most commonly used autografts are hamstring tendon grafts, bone–patellar tendon–bone (BPTB) grafts, and quadriceps tendon grafts.

Hamstring tendon grafts are often associated with less anterior knee pain and lower donor-site morbidity, although some studies suggest slightly greater postoperative laxity compared with BPTB grafts. Bone–patellar tendon–bone grafts are valued for strong fixation and reliable stability, which is why they are frequently considered in high-level athletes; however, they may be associated with anterior knee pain and patellar complications [27].

Quadriceps tendon grafts have gained popularity in recent years and are increasingly considered a useful alternative, offering favorable biomechanical properties and acceptable donor-site morbidity in selected patients.

Surgical techniques

Current surgical techniques aim to reproduce native ACL anatomy as closely as possible. Single-bundle anatomic reconstruction remains the most commonly performed procedure, while double-bundle techniques have been proposed to improve restoration of rotational stability.

Although some biomechanical studies suggest possible advantages of double-bundle reconstruction, clinical outcomes are often broadly comparable with those seen after single-bundle procedures [28]. In practice, the choice of technique usually depends on surgeon experience, patient anatomy, and individual clinical considerations.

Most ACL reconstructions are now performed arthroscopically, which has reduced postoperative morbidity and facilitated early recovery.

Timing of surgery

The optimal timing of ACL reconstruction remains a matter of debate. Early surgery may shorten the period of instability and potentially reduce the risk of secondary meniscal or chondral injury. On the other hand, delayed reconstruction combined with appropriate rehabilitation may be suitable in selected patients.

In current practice, timing is usually decided on an individual basis, taking into account knee function, symptoms of instability, sport-specific demands, associated injuries, and patient priorities.

Rehabilitation after reconstruction

Rehabilitation is a fundamental part of ACL treatment and, in many cases, influences the final outcome as much as the operation itself. Even a technically successful reconstruction may lead to suboptimal functional recovery if rehabilitation is poorly designed, inadequately supervised, or inconsistently followed.

Early rehabilitation usually focuses on pain and swelling control, restoration of knee extension and range of motion, and activation of the quadriceps muscle. As recovery progresses, the emphasis shifts toward strengthening, neuromuscular control, balance, and restoration of functional movement patterns.

In later stages, rehabilitation becomes increasingly sport-specific and may include plyometric exercises, change-of-direction drills, landing retraining, and dynamic stability tasks [29]. Progression should be guided by functional recovery rather than by arbitrary timelines alone. Premature advancement, poor adherence, or insufficient assessment of residual deficits may compromise recovery and increase the risk of graft failure or secondary injury. It is also important to recognize that some athletes continue to show deficits in strength, coordination, or movement quality even when they appear clinically recovered.

Emerging and adjunctive therapies

Biological augmentation strategies such as platelet-rich plasma (PRP), stem cell-based approaches, and other regenerative methods have received increasing attention in recent years. These interventions aim to enhance graft healing, reduce inflammation, and potentially improve recovery. However, the available evidence remains inconsistent, and such therapies are not currently considered standard components of ACL management [30]. Overall, treatment of ACL injury in athletes requires more than a technically successful operation. The best outcomes are achieved when surgery, rehabilitation, and return-to-sport planning are integrated into one individualized strategy.

6. Return to Sport (RTS) After ACL Injury

Return to sport is one of the most important, and at the same time most challenging, aspects of ACL injury management. For many athletes, it is the primary reason for pursuing treatment. However, it also represents one of the most difficult clinical decisions, because returning too early may expose the athlete to a substantial risk of re-injury, whereas unnecessary delay may negatively affect performance, confidence, and career progression.

Time-based versus criteria-based RTS

Traditionally, return-to-sport decisions were often based mainly on the number of months that had passed since surgery, with many athletes returning between 6 and 12 months after reconstruction. This time-based model, however, has important limitations. Recovery after ACL injury is highly individual, and time alone provides little information about strength, movement quality, neuromuscular control, or psychological readiness [14,31]. For this reason, current thinking increasingly favors a criteria-based approach. Rather than asking only whether enough time has passed, clinicians are encouraged to determine whether the athlete has achieved a broader set of objective and functional milestones.

Physical and functional criteria

Restoration of sufficient muscle strength is one of the most important prerequisites for safe RTS. A commonly used benchmark is at least 90% limb symmetry in quadriceps and hamstring strength compared with the contralateral side [32]. Even so, symmetry should be interpreted cautiously, because both limbs may be deconditioned after a prolonged period away from sport. Functional performance tests such as the single-leg hop, triple hop, and crossover hop are commonly used to assess power, dynamic control, and asymmetry [33]. These tests are valuable, but movement quality during testing may be just as important as the numerical result. An athlete may achieve acceptable hop distance while still demonstrating poor landing mechanics, inadequate force absorption, or dynamic valgus. Such deficits may increase the likelihood of re-injury despite satisfactory test scores. For this reason, qualitative movement analysis has become an increasingly important part of RTS assessment. Neuromuscular control and proprioception also deserve attention, since both are essential for maintaining joint stability during high-demand sport-specific actions [19].

Psychological readiness

Physical recovery alone does not guarantee readiness to return. Psychological factors may strongly influence whether athletes resume sport and whether they regain their previous performance level. Fear of re-injury, reduced confidence, hesitation during demanding movements, and more general performance-related anxiety are all common after ACL reconstruction [15]. The ACL-Return to Sport after Injury (ACL-RSI) scale is frequently used to assess this aspect of recovery [34]. Greater psychological readiness has been associated with better RTS outcomes, which suggests that rehabilitation should address emotional and cognitive factors alongside physical deficits.

Risk of secondary injury

One of the most serious concerns after RTS is the risk of sustaining another ACL injury. Younger and highly active athletes seem to be particularly vulnerable, with studies suggesting that up to 20–30% may experience a second ACL injury, either in the reconstructed knee or in the contralateral limb [16,35].

Returning to sport before adequate recovery has been achieved significantly increases this risk. In particular, return before 9 months after surgery has been associated with a markedly higher re-injury rate [31]. Residual strength deficits, impaired neuromuscular control, movement asymmetries, and suboptimal rehabilitation likely all contribute to this problem.

Return to pre-injury performance

Although many athletes eventually return to some form of sports participation, a smaller proportion regain their previous level of performance. Available evidence suggests that approximately 60–70% return to their pre-injury level of sport [5]. This means that even when treatment is regarded as clinically successful, full sporting recovery is far from guaranteed. Age, type of sport, competition level, rehabilitation quality, and psychological readiness all seem to influence this outcome. Athletes participating in cutting and pivoting sports may face particular difficulty in regaining both confidence and performance.

Contemporary approaches to RTS

Modern RTS models increasingly emphasize that return should be gradual, monitored, and individualized. No single test and no single time point is sufficient to determine readiness. Instead, decision-making should integrate strength measures, functional test performance, movement quality, symptom status, and psychological preparedness. New technologies, including motion analysis systems and wearable sensors, may provide more objective information about persistent movement deficits during sport-specific tasks. Although these tools are not yet universally available, they may improve the precision of RTS decision-making in the future.

Even after return to competition, continued neuromuscular and injury-prevention training remains important in order to reduce the likelihood of subsequent ACL injury. In summary, return to sport after ACL injury should be understood as a process rather than a single event. Safe and successful RTS depends on meeting multiple criteria, not simply on allowing time to pass.

7. Discussion

ACL injuries remain one of the central challenges in sports medicine, not only because of their frequency, but also because of the complexity of their causes and the potentially long-lasting consequences that may follow. The literature reviewed in this paper supports the view that ACL injury is not a single-factor problem. Instead, it results from the interaction of anatomical, neuromuscular, biomechanical, hormonal, and environmental influences, which together shape both injury risk and recovery.

One of the most consistent findings in the literature is the predominance of non-contact injury mechanisms. This has major clinical significance. If injury commonly occurs during faulty movement rather than through unavoidable trauma, then at least part of the risk may be modifiable. The repeated association between ACL rupture and factors such as dynamic knee valgus, limited knee flexion, and poor trunk control strongly supports the use of neuromuscular prevention programs, especially in athletes considered to be at increased risk [8,11,12,20]. At the same time, treatment outcomes make it clear that restoring mechanical knee stability is only one part of the broader clinical picture. Surgical reconstruction remains the standard approach for many athletes wishing to return to demanding sports, but surgery alone does not guarantee full functional recovery. Rehabilitation plays a decisive role in restoring strength, movement quality, confidence, and sport-specific performance. This is particularly important because many athletes who appear to recover well during routine clinical assessment may still demonstrate meaningful deficits when examined with more detailed functional testing. The discrepancy between apparent clinical recovery and true functional readiness is one of the key issues in contemporary ACL management. An athlete may have regained range of motion, report minimal symptoms, and present with an apparently stable knee, while still showing altered movement patterns, strength asymmetries, or impaired neuromuscular control. These deficits may help explain why the rate of secondary ACL injury remains high, particularly among younger athletes returning to competitive sport.

Another important problem is the lack of universally accepted RTS criteria. Although there has been a clear move toward criteria-based decision-making, substantial variability still remains in clinical practice. Time since surgery continues to strongly influence RTS decisions, even though increasing evidence shows that it is not an adequate indicator on its own. This inconsistency may contribute to premature return and, as a result, unnecessary re-injury risk. Psychological recovery also deserves greater attention than it often receives. Fear of re-injury, reduced confidence, and hesitation during high-demand movements may persist long after physical healing and may become major barriers to successful return to sport. In some athletes, these factors may be just as important as strength or mechanical stability in determining whether they return to their previous level.

The long-term consequences of ACL injury remain another major concern. Even after apparently successful treatment, the risk of post-traumatic osteoarthritis remains elevated [6,7]. This suggests that current treatment strategies, while often effective in restoring short-term stability and function, do not fully eliminate the long-term burden of injury. From a clinical point of view, these findings support an individualized and multidisciplinary approach. Athletes differ considerably with respect to age, sport-specific demands, injury characteristics, response to rehabilitation, and psychological readiness. Management should therefore be tailored to the individual rather than based on rigid assumptions. This review has several limitations. As a narrative review, it does not provide the same methodological rigor as a systematic review and is therefore more vulnerable to selection bias. In addition, the included studies vary considerably in design, patient characteristics, and outcome measures, which limits the strength of broad conclusions. Future research should focus on refining RTS criteria, improving individualized rehabilitation strategies, and exploring treatment approaches that may improve both short-term recovery and long-term joint health. More long-term follow-up studies are also needed to identify which athletes remain at greatest risk of repeated injury and post-traumatic osteoarthritis. Overall, ACL injury in athletes should not be viewed simply as an isolated ligament rupture. It is better understood as part of a broader clinical process that begins before the injury occurs and may continue to affect the athlete long after return to sport.

8. Clinical Implications

The findings of this review have several practical implications for everyday clinical work. First, injury prevention should be treated as an integral part of athletic preparation rather than as an optional addition to training. Neuromuscular programs aimed at improving balance, coordination, landing mechanics, trunk control, and lower limb alignment should be implemented particularly in sports associated with a high incidence of ACL injury.

Second, return-to-sport decisions should not rely only on time since surgery. Before an athlete is cleared for unrestricted participation, clinicians should combine strength testing, functional assessment, movement quality analysis, and psychological evaluation.

Third, rehabilitation should be seen as a central element of treatment rather than merely a postoperative routine. A well-structured and progressive rehabilitation program is essential for minimizing persistent deficits and reducing the risk of secondary injury.

Finally, athletes who sustain ACL injury should continue to be monitored even after they have returned to play. Ongoing follow-up may help identify persisting dysfunction and may also be important in the context of long-term joint degeneration and post-traumatic osteoarthritis.

9. Future Directions

Future research should continue to focus on improving both short-term and long-term outcomes after ACL injury. One of the main priorities is the development of more standardized, evidence-based RTS criteria that combine physical testing, movement analysis, and psychological readiness.

Further work is also needed to clarify how rehabilitation can be better individualized, taking into account age, sex, sport-specific demands, and level of competition. Advances in motion analysis, sensor technology, and biomechanical assessment may improve the identification of persistent deficits and allow more precise monitoring of recovery.

Biological augmentation strategies, including PRP and cell-based therapies, also require further high-quality investigation before they can be confidently recommended as part of routine clinical practice. In addition, long-term observational studies are needed to better define the relationship between ACL injury, reconstruction, recurrent instability, and later osteoarthritis.

Greater emphasis should also be placed on the large-scale implementation of prevention programs, as reducing the number of primary injuries remains one of the most effective ways to improve outcomes in this field.

10. Conclusions

ACL injuries in athletes remain a major clinical problem because of their frequency, multifactorial background, and potentially long-term consequences. Current evidence indicates that these injuries result from the interaction of multiple intrinsic and extrinsic factors, with neuromuscular control and biomechanical patterns playing particularly important roles. Because most ACL ruptures occur through non-contact mechanisms, preventive strategies targeting modifiable risk factors are especially important. Neuromuscular training, movement correction, and strength development should therefore be regarded as essential elements of athletic preparation.

Management should always be individualized. Although ACL reconstruction remains the preferred treatment for many athletes participating in high-demand sports, successful outcomes depend heavily on high-quality rehabilitation and carefully planned return-to-sport progression.

Return to sport should be based on objective criteria rather than on time alone. Strength, function, movement quality, and psychological readiness all need to be considered in order to reduce the risk of re-injury.

Despite advances in treatment and rehabilitation, many athletes do not return to their previous level of performance, and the risk of a second ACL injury remains considerable. In addition, the long-term possibility of post-traumatic osteoarthritis underlines the need for continued follow-up and preventive care.

In conclusion, effective management of ACL injury requires more than surgical reconstruction alone. It calls for an integrated approach that combines prevention, individualized rehabilitation, and careful return-to-sport decision-making.

11. Disclosure

11.1 Author Contribution

Conceptualization: Krzysztof Bednarski and Natalia Kornacka;
Methodology: Krzysztof Bednarski, Melania Majewska and Martyna Kaim
Validation: Izabela Rafalska, Martyna Kaim, and Natalia Piasecka
Formal analysis: Izabela Rafalska and Natalia Piasecka

Investigation: Joanna Bober, Magdalena Bochenek
Resources: Wiktoria Siewiera and Jakub Smagoń
Data curation: Krzysztof Bednarski, Jakub Smagoń and Joanna Bober
Writing - original draft preparation: Wiktoria Siewiera, Natalia Kornacka
Writing - review and editing: Krzysztof Bednarski and Magdalena Bochenek
Supervision, Natalia Kornacka and Melania Majewska
Project administration: Krzysztof Bednarski
All authors have read and agreed to the published version of the manuscript

11.2 Funding statement

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11.3 Institutional Review Board Statement

Not Applicable.

11.4 Conflict of Interest Statement

The authors report no conflict of interest.

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