Review Article

Early versus Late Functional Outcomes After Anterior Cruciate Ligament Reconstruction in Athletes: A Comparative Analysis

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Abstract

Anterior cruciate ligament reconstruction is a common intervention in athletic populations, aiming to restore knee stability, functional performance, and safe return to sport. Despite advances in surgical techniques and rehabilitation protocols, the optimal timing of reconstruction and its influence on functional outcomes remain subjects of ongoing debate. This review synthesizes current evidence comparing early and late functional outcomes following anterior cruciate ligament reconstruction in athletes, with emphasis on biomechanical recovery, return-to-sport dynamics, reinjury risk, and long-term joint health. The anatomical and biomechanical complexity of the anterior cruciate ligament underscores its essential role in knee stability, proprioception, and neuromuscular control, all of which are critical determinants of postoperative function. Early reconstruction has been associated with

faster short-term recovery, including improved quadriceps strength, neuromuscular control, and earlier return to sport. However, these early advantages tend to converge over time, as long-term functional scores, knee stability, and performance levels appear similar between early and delayed reconstruction groups. Return-to-sport rates are influenced by multiple factors, including age, sex, type of sport, level of competition, graft selection, and adherence to structured rehabilitation programs. Psychological readiness and fear of reinjury emerge as key determinants of successful return to sport, independent of physical recovery. Although long-term knee function is generally maintained after reconstruction, the risk of reinjury and the progression of degenerative joint changes, including osteoarthritis, remain important concerns, particularly in younger and highly active athletes. Overall, functional recovery after anterior cruciate ligament reconstruction reflects a complex interaction between surgical timing, biological healing, rehabilitation quality, and psychological factors. An individualized, criteria-based approach to rehabilitation and return-to-sport decision-making is essential to optimize athletic performance while minimizing long-term complications.

Key words

Knee stability, neuromuscular control, proprioception, graft selection, reinjury risk, osteoarthritis progression.

Introduction

Anterior cruciate ligament injuries are particularly prevalent in athletic populations, especially among young athletes, who account for approximately half of all reported cases, including those competing at the collegiate level [1]. The incidence of injury is not uniform across sports, but instead varies according to the specific physical and biomechanical demands involved. Higher rates have consistently been reported in sports that require frequent pivoting, cutting, and rapid deceleration, such as soccer, basketball, and football [2]. Within elite settings, this burden is clearly illustrated in professional European soccer, where the mean annual incidence of anterior cruciate ligament injury has been estimated at 1.42%, underscoring the substantial exposure of high-performance athletes to this condition [3].

Beyond its immediate clinical significance, rupture of the anterior cruciate ligament has profound implications for athletic performance and career longevity. In professional soccer players, anterior cruciate ligament reconstruction has been associated with a measurable reduction in minutes played per season following surgery, reflecting a decline in sustained competitive participation (Mazza et al., 2022). Although return-to-play rates are generally high, long-term performance outcomes appear less favorable, as only 34% of athletes are able to compete at the same or a higher league level five years after reconstruction [4]. This trend is not limited to elite athletes, as recreational populations also demonstrate limited functional recovery, with only approximately half of individuals increasing their activity level and successfully returning to sport following reconstruction [5].

Evaluating functional outcomes across different postoperative timeframes becomes essential for understanding both the recovery trajectory and the true long-term success of anterior cruciate ligament reconstruction. Assessments conducted at multiple stages after surgery provide insight into how knee function, performance capacity, and athletic participation evolve over time [2]. Importantly, longer follow-up periods appear necessary to accurately capture return-to-sport outcomes, as return rates tend to increase progressively with time rather than stabilizing early after surgery [5]. However, timing also introduces trade-offs, as early return to play, defined as occurring within six months in professional soccer players, has been associated with longer career duration but simultaneously

confers a higher risk of graft failure, emphasizing the complex balance between performance optimization and injury risk [6].

Within the existing literature, early and late outcomes after anterior cruciate ligament reconstruction are therefore defined according to distinct temporal frameworks that reflect different clinical priorities. Early outcomes are typically evaluated within the first six months following surgery and primarily focus on initial recovery, functional restoration, and the ability to resume sporting activity [6]. In contrast, late outcomes extend beyond six months and often encompass several years of follow-up, allowing for assessment of long-term performance, career longevity, and the risk of re-injury or graft failure [7]. This temporal distinction is critical, as it informs the interpretation of functional results and supports the development of rehabilitation strategies and expectation-setting that are aligned with both short-term recovery goals and long-term athletic sustainability [8].

The aim of this article is to compare early and late functional outcomes following anterior cruciate ligament reconstruction in athletes, with particular emphasis on return to sport, performance sustainability, and injury-related risk over time.

Methodology

This narrative review on early versus late functional outcomes after anterior cruciate ligament reconstruction in athletes was developed through a structured examination of contemporary scientific evidence, with the objective of integrating clinical, functional, and performance-related outcomes across different postoperative timeframes. The methodological framework was designed to emphasize temporal comparisons, focusing on short-term versus long-term recovery, return-to-sport dynamics, and the evolution of athletic performance and injury risk following reconstruction.

A comprehensive literature search was conducted using PubMed, Scopus, and Web of Science, including peer-reviewed articles published between 2021 and 2026 in English or Spanish. Eligible studies addressed key aspects of anterior cruciate ligament reconstruction in athletic populations, including early and late functional outcomes, return-to-sport rates, performance metrics, career longevity, reinjury risk, and factors influencing postoperative recovery. Studies lacking peer review, presenting incomplete or redundant data, or not directly evaluating functional outcomes in relation to postoperative timing were excluded. The search strategy was guided by predefined terms such as Knee stability, neuromuscular control, proprioception, graft selection, reinjury risk, osteoarthritis progression.

The selected literature was analyzed using a qualitative and integrative approach to identify temporal trends in functional recovery, differences between early and late postoperative outcomes, and clinically relevant patterns influencing athletic performance and long-term knee health. Emphasis was placed on synthesizing evidence related to outcome assessment timing, rehabilitation implications, and return-to-sport decision-making. Artificial intelligence–based tools were used as supportive aids to facilitate thematic organization and to enhance coherence across clinical and functional domains. This methodological approach enabled the development of a logically connected synthesis of current evidence, highlighting the importance of time-sensitive evaluation when interpreting functional outcomes and guiding clinical management in athletes undergoing anterior cruciate ligament reconstruction.

Anatomy and Biomechanics of the Anterior Cruciate Ligament

The anterior cruciate ligament is a dynamic structure characterized by a rich neurovascular supply and the presence of distinct bundles that together form a complex three-dimensional architecture. This anatomical configuration

allows the ligament to function in close synergy with the bony morphology of the knee, facilitating normal joint kinematics and coordinated motion under physiological conditions [9]. On the tibial side, the ligament demonstrates broad attachment sites that extend beyond the osseous surface to include the articular cartilage and the lateral meniscus. This anatomical integration suggests a more comprehensive role in knee joint mechanics than was previously appreciated, reinforcing the concept of the anterior cruciate ligament as a key contributor to overall joint function rather than an isolated stabilizing structure [10]. Within this framework, the native dimensions and spatial orientation of the ligament are critical determinants of its biomechanical performance, as variations in these parameters can substantially influence postoperative knee stability and the success of reconstructive procedures [11].

Functionally, the anterior cruciate ligament serves as the primary stabilizer against anterior translation of the tibia and plays a significant role in controlling internal rotation of the knee, particularly when the joint is near full extension [12]. Beyond its mechanical contribution, the ligament is integral to proprioceptive regulation, providing essential somatosensory input required for accurate joint positioning and coordinated movement control. Injury to the ligament or alterations following reconstruction can impair this proprioceptive function, leading to deficits in neuromuscular control that compromise knee stability and overall functional performance [13]. In maintaining rotational stability, the anterior cruciate ligament operates in conjunction with adjacent structures, including the anterolateral complex, underscoring its central role within a broader stabilizing network that preserves physiological knee mechanics [12].

During athletic activities, the biomechanical demands placed on the anterior cruciate ligament are substantial, particularly during movements such as landing from a jump, rapid changes in direction, or sudden deceleration. These actions expose the ligament to combined loading patterns that include anterior tibial shear forces, internal tibial torque, and knee abduction moments, which together markedly increase the risk of injury [14]. In specific athletic disciplines such as weightlifting, the ligament may be subjected to atypical mechanical environments, as observed during the jerk dip phase, where abnormal stress distributions can predispose the ligament to injury. Recognizing and characterizing these stress patterns is therefore essential for the development of targeted preventive strategies [15]. From a mechanical standpoint, ligament failure may occur as a result of a single supramaximal loading event or through the cumulative effect of repeated submaximal loading cycles, which progressively generate microdamage and ultimately compromise structural integrity over time [14].

Indications and Surgical Techniques for Anterior Cruciate Ligament Reconstruction

In athletic populations, the primary indication for anterior cruciate ligament reconstruction is the presence of knee instability, which compromises performance and substantially increases the risk of secondary injuries. Persistent instability not only limits functional capacity during sport-specific movements but also predisposes the knee to additional structural damage. In this context, technical factors such as tunnel malposition and tunnel widening have been identified as common causes of persistent instability and represent frequent indications for revision procedures following primary reconstruction [16]. Alongside mechanical instability, the athlete’s activity level plays a decisive role in surgical decision-making, as individuals engaged in high-demand, pivoting sports are more likely to require reconstruction in order to safely return to their pre-injury level of competition [17]. Age and projected future activity further influence this decision, with younger athletes who anticipate prolonged

athletic careers often being recommended for reconstruction to preserve joint function, reduce the risk of progressive degeneration, and maintain long-term performance capacity [18].

The selection of graft type represents a critical component of surgical planning and is closely linked to both functional outcomes and rehabilitation trajectories. Among autografts, the bone–patellar tendon–bone and hamstring tendon grafts are the most used options. Bone–patellar tendon–bone autografts are frequently favored due to their inherent strength and capacity to provide robust knee stability; however, their use has been associated with longer rehabilitation periods when compared with hamstring tendon grafts [19]. In contrast, hamstring tendon autografts are widely preferred in many regions because they are associated with lower donor-site morbidity and may facilitate a quicker recovery, making them an attractive option for athletes seeking an earlier functional return [20]. Allografts, by comparison, are more commonly utilized in older patients or in cases involving multiple ligament injuries. While they offer advantages such as reduced operative time and the absence of donor-site morbidity, their use in younger and highly active athletes has been associated with a slightly increased risk of graft failure, which limits their applicability in this population [18].

From a technical perspective, several surgical approaches are routinely employed in anterior cruciate ligament reconstruction, each aiming to optimize anatomical restoration and functional outcomes. Single-bundle reconstruction remains the most performed technique and involves the placement of a single graft to restore ligament function, whereas double-bundle reconstruction seeks to more closely replicate the native anatomy of the ligament by reconstructing its distinct functional bundles [21]. More recently, the all-inside technique has gained attention, as it relies on the creation of bone sockets rather than full-length tunnels, thereby preserving bone stock and reducing postoperative pain. This approach has demonstrated outcomes that are comparable to, or in some cases superior to, those of traditional techniques [22]. Fixation methods further influence surgical stability and healing, with commonly used options including interference screws and suspensory fixation. Interference screws provide strong initial fixation but may contribute to tunnel widening, whereas suspensory fixation is less invasive yet may allow increased graft–tunnel motion during early healing phases [23].

These surgical variables have direct implications for postoperative rehabilitation and return-to-play strategies. The choice of graft significantly influences recovery timelines, as bone–patellar tendon–bone grafts often require longer periods to achieve strength symmetry when compared with hamstring tendon grafts [19]. Similarly, surgical techniques that minimize tissue trauma, such as the all-inside approach, may facilitate a faster recovery by reducing postoperative pain and swelling [22]. Techniques employing shorter graft constructs have also been proposed to preserve muscle strength and further shorten recovery time [24]. Regardless of the specific graft or technique used, the success of reconstruction ultimately depends on the implementation of a structured and progressive rehabilitation program. Return-to-play rates vary considerably, with graft selection, surgical approach, and psychological readiness emerging as key determinants of successful functional recovery in athletes [17].

Definition and Assessment of Functional Outcomes

Clinical and functional outcomes following anterior cruciate ligament reconstruction are commonly evaluated using standardized assessment tools that allow for a structured appraisal of knee function and activity level. Among these, the International Knee Documentation Committee form and the Tegner activity scale are frequently employed, as they provide complementary information regarding subjective knee function and the degree of

activity participation after reconstruction. These instruments enable clinicians to quantify recovery in a reproducible manner and to monitor changes in functional status across different postoperative stages. In parallel, functional outcomes are assessed through performance-based tests, including single-leg and triple hop tests for distance, as well as isokinetic strength evaluations, which collectively offer objective measures of limb symmetry and muscular strength restoration [25].

In addition to clinician-administered and performance-based measures, patient-reported outcome measures play a central role in the comprehensive evaluation of postoperative recovery. Tools such as the Anterior Cruciate Ligament Return to Sport after Injury score are particularly valuable for capturing the athlete's psychological readiness and perceived knee function, domains that are not fully reflected by physical testing alone [25]. These subjective assessments provide insight into confidence, fear of reinjury, and self-perceived functional capacity, thereby contributing to a more holistic understanding of recovery from the athlete's perspective [26].

Objective performance-based assessments further enhance outcome evaluation by incorporating advanced methodologies that extend beyond traditional functional testing. Biomechanical analyses and emerging technologies, including magnetic resonance imaging, have been increasingly utilized to assess graft integrity, joint loading patterns, and neuromuscular control, with the potential to improve prediction of reinjury risk and readiness for return to sport [27]. Such objective evaluations are critical for confirming that athletes have regained sufficient physical capacity to safely perform sport-specific movements and tolerate the demands of competitive activity [2].

Despite the availability of multiple assessment modalities, criteria for return to sport remain heterogeneous and lack universal standardization. Decisions regarding return to play are typically based on an integrated interpretation of clinical findings, functional performance, and psychological readiness, and must be individualized according to the athlete's recovery trajectory and the specific demands of their sport. In this context, a greater emphasis on objective, criteria-based milestones has been advocated to optimize the likelihood of safely returning athletes to their preinjury level of function while minimizing the risk of reinjury [2, 27].

Early Functional Outcomes After Reconstruction

The short-term recovery timeline following anterior cruciate ligament reconstruction in athletes is characterized by a structured and progressive rehabilitation process aimed at restoring knee function and facilitating a safe return to sport. On average, athletes return to sporting activity at approximately 7.9 months after surgery, although this timeframe varies considerably depending on individual characteristics and the specific rehabilitation protocols employed [28]. Early in the postoperative period, key recovery milestones include the achievement of full knee extension, effective control of joint swelling, and the restoration of quadriceps strength, all of which are essential for functional progression. In this context, acute reconstruction has been associated with superior quadriceps strength at three months postoperatively when compared with delayed procedures, suggesting potential advantages of earlier surgical intervention in the initial recovery phase [8].

During the early postoperative stage, knee stability, muscular strength, and range of motion represent critical determinants of functional recovery. Available evidence indicates that there are no significant differences in knee joint stability or range of motion when comparing different timing groups of reconstruction, highlighting the overall effectiveness of contemporary surgical and rehabilitation

strategies in restoring these parameters [8]. Despite this, quadriceps strength remains a persistent challenge, as many athletes fail to achieve the commonly recommended limb symmetry index of 90% or greater in the early phases of rehabilitation [28]. Notably, athletes undergoing acute reconstruction tend to demonstrate more favorable early strength outcomes, reinforcing the relevance of surgical timing in short-term functional recovery [8].

Rates of early return to sport and associated performance levels vary substantially across athletic populations. In recreational athletes, only approximately half are able to return to their previous level of activity, reflecting the combined influence of physical limitations and psychosocial factors on early recovery [5]. In contrast, higher return-to-sport rates have been reported in competitive populations, such as wrestlers, among whom up to 80% successfully resume sporting participation [29]. However, even when return to sport is achieved, performance may be compromised by residual functional deficits, including reduced knee flexion angles and altered movement biomechanics, which can persist during the early follow-up period and affect athletic efficiency [28].

Despite advances in surgical techniques and rehabilitation protocols, early follow-up after reconstruction remains associated with specific complications and limitations. Graft failure and residual knee instability continue to be clinically relevant concerns, with graft selection playing a significant role in outcome variability. Bone–patellar tendon–bone autografts have been shown to exhibit lower failure rates compared with hamstring tendon autografts, particularly in high-demand athletic populations [29]. Moreover, limitations in early recovery highlight the need for more robust and individualized rehabilitation strategies that account for athlete-specific factors such as age, sex, and the biomechanical demands of different sports, thereby optimizing early outcomes and reducing the risk of adverse events [30].

Late Functional Outcomes After Reconstruction

Long-term follow-up after anterior cruciate ligament reconstruction demonstrates that improvements in knee function and stability are generally maintained over time. Functional outcomes assessed using International Knee Documentation Committee scores indicate a sustained recovery trajectory, with reported return-to-sport rates of approximately 70% and an 87% likelihood of maintaining knee stability during physical activity at eight years postoperatively [31]. Advances in surgical strategies have further contributed to long-term stability, as combined reconstruction of the anterior cruciate ligament and the anterolateral ligament has been shown to result in reduced residual knee laxity and lower graft failure rates when compared with isolated anterior cruciate ligament reconstruction, suggesting an enhanced capacity to preserve joint stability in the long term [32].

In parallel with sustained knee function, the long-term sustainability of athletic performance following reconstruction appears favorable in many athletic populations. High return-to-play rates have been documented, including in Gaelic games players, among whom an 87.8% return rate has been reported, often at an equivalent or even higher level of performance compared with preinjury status. Nevertheless, performance sustainability is influenced by surgical variables, particularly graft selection, as bone–patellar tendon–bone autografts have been associated with lower reinjury rates than hamstring autografts, thereby supporting more durable athletic participation over time [33].

Despite these encouraging outcomes, reinjury remains a significant concern in the long-term postoperative period. Reported rates include a 7.2% incidence of revision surgery and a 6% probability of contralateral anterior cruciate

ligament reconstruction within nine years following the initial procedure [31]. The risk of reinjury is not uniformly distributed across populations, with younger athletes and those reconstructed using hamstring autografts demonstrating a higher susceptibility to subsequent ligament injury [33].

Beyond ligamentous integrity, the development of degenerative joint changes represents a critical long-term consideration after anterior cruciate ligament reconstruction. Longitudinal studies have shown a significantly increased progression of osteoarthritis in reconstructed knees compared with healthy contralateral knees, with a reported relative risk of 2.8, highlighting the persistent vulnerability of the operated joint. Several factors have been identified as contributors to this increased risk, including delayed surgical intervention, the presence of concomitant meniscal or cartilage injuries, and higher levels of postoperative physical activity, all of which may accelerate degenerative processes over time [34, 35].

Comparison Between Early and Late Outcomes

Functional recovery after anterior cruciate ligament reconstruction is commonly quantified using validated scoring systems such as the Tegner activity score and the Lysholm score, which allow comparison of functional status across different postoperative timeframes. Evidence suggests that early reconstruction is associated with more favorable short-term functional outcomes, including greater quadriceps strength and superior performance in tasks such as the single-leg hop test, reflecting an accelerated recovery during the initial postoperative period [8]. However, when functional outcomes are evaluated over longer follow-up intervals, these early advantages appear to diminish, as long-term assessments reveal no significant differences between early and late reconstruction groups. This convergence is demonstrated by comparable scores on the International Knee Documentation Committee Subjective Knee Form and the Knee injury and Osteoarthritis Outcome Score at five years following surgery, indicating similar long-term functional status regardless of surgical timing [37].

The temporal pattern observed in functional scores parallels the evolution of neuromuscular control and proprioception after reconstruction. Early surgical intervention has been associated with a more rapid restoration of these mechanisms, which are essential for safe participation in athletic activities. Athletes undergoing early reconstruction tend to exhibit improved quadriceps strength and enhanced performance in functional tests during the early recovery phase, supporting the notion of accelerated neuromuscular adaptation [8]. Despite these short-term benefits, longitudinal data suggest that neuromuscular control and proprioceptive function eventually stabilize, with no meaningful differences detected between early and late reconstruction groups during long-term follow-up [37].

The timing of anterior cruciate ligament reconstruction also has a direct impact on the return to pre-injury performance levels. Early reconstruction has been shown to facilitate a faster return to sport, with reported mean return-to-play times of approximately 292 days following surgery, highlighting its potential advantage for athletes seeking expedited competitive reentry [36]. Nevertheless, this accelerated timeline is accompanied by an increased risk of reinjury, particularly when return-to-sport testing is conducted prematurely. These observations emphasize the need to balance the benefits of earlier return with adequate biological healing and neuromuscular recovery to mitigate the risk of subsequent injury [38].

From a clinical standpoint, these findings hold important implications for athletes and sports medicine teams. A clear understanding of the effects of surgical timing on functional recovery

enables more accurate expectation setting and supports the optimization of individualized rehabilitation strategies. While early reconstruction may be advantageous for athletes who require a rapid return to competition, it necessitates meticulous rehabilitation planning and vigilant monitoring to reduce reinjury risk [8, 38]. Ultimately, the decision between early and late reconstruction should be tailored to the individual athlete, considering sport-specific demands, personal recovery goals, and the long-term preservation of joint health and performance sustainability [2].

Factors Influencing Functional Outcomes

Functional outcomes after anterior cruciate ligament reconstruction are influenced by a range of individual and sport-related factors, among which age, sex, and type of sport play prominent roles. Younger athletes, particularly those under 19 years of age, demonstrate a higher likelihood of returning to their pre-injury level of sport, a finding commonly attributed to superior biological healing capacity and higher levels of motivation during rehabilitation [39]. Sex-related differences have also been observed, with male athletes generally exhibiting higher return-to-sport rates than their female counterparts. This disparity has been documented in specific athletic populations, such as Gaelic games, where male athletes achieved higher return-to-play rates compared with females [33]. In addition, the type of sport exerts a substantial influence on postoperative outcomes, as sports characterized by high physical demands, including wrestling and Australian football, are associated with lower return-to-sport rates when compared with less physically demanding sports such as basketball [29, 36].

Beyond individual characteristics, the level of competition and training load further modulate recovery trajectories and return-to-play outcomes. Elite and professional athletes consistently demonstrate high return-to-sport rates, often exceeding 85%, a pattern that is likely related to enhanced access to specialized medical care, structured rehabilitation resources, and strong extrinsic motivation to resume competition [36]. In contrast, collegiate athletes, particularly those competing in Division II and III programs, show less favorable outcomes, with only approximately half returning to their pre-injury level of participation, highlighting disparities in support systems and performance demands across competitive levels. Training load represents an additional consideration, as athletes exposed to higher workloads may subject the reconstructed ligament to increased mechanical stress, potentially influencing return-to-sport outcomes. Nevertheless, detailed data quantifying the specific impact of training load remain limited within the current literature [17].

The structure and implementation of rehabilitation protocols are central determinants of functional recovery and successful return to sport. Adherence to well-defined rehabilitation programs that incorporate progressive strength training, functional performance testing, and assessments of psychological readiness has been associated with more favorable return-to-play outcomes [30]. Compliance with these protocols appears to be equally important, as athletes who consistently adhere to prescribed rehabilitation regimens demonstrate superior functional outcomes and higher rates of return to sport. Conversely, non-adherence has been linked to suboptimal recovery and an elevated risk of reinjury, underscoring the importance of sustained engagement throughout the rehabilitation process [40].

Psychological readiness represents a critical yet often underappreciated component of recovery after anterior cruciate ligament reconstruction. Factors such as self-efficacy and confidence in the reconstructed knee significantly influence an athlete’s ability to return to sport, with higher psychological readiness scores correlating with increased likelihood of successful return. Fear of reinjury, in particular, can act as a substantial barrier, preventing athletes from resuming sport despite adequate physical recovery. Addressing

these psychological factors through targeted interventions is therefore essential to achieving a successful and durable return to sport [41].

Conclusions

The anatomy and biomechanics of the anterior cruciate ligament explain its central role not only in mechanical knee stability but also in proprioception and neuromuscular control, supporting the concept that precise anatomic reconstruction, surgical technique, and graft selection directly influence both early and late functional outcomes after reconstruction.

Early anterior cruciate ligament reconstruction is associated with clear advantages during the initial recovery phase, including faster restoration of quadriceps strength, neuromuscular control, and return to sport; however, these early benefits tend to diminish over long-term follow-up, as overall functional outcomes and knee stability become comparable between early and late reconstruction.

Functional recovery and sustained return to sport depend on a complex interaction of surgical, biological, functional, and psychological factors, underscoring the importance of structured rehabilitation, objective return-to-sport criteria, and adequate psychological readiness to optimize athletic performance while minimizing the risks of reinjury and long-term joint degeneration.

References

1. Dewig D, Chandran A, Boltz A, Robison H, Collins CL, Blackburn T. Epidemiology of anterior cruciate ligament injuries in National Collegiate Athletic Association Athletes: 2014/15 - 2018/19. Medicine &Science In Sports&Exercise [Internet]. 1 de septiembre de 2022;54(9S):637-8. Disponible en: https://doi.org/10.1249/01.mss.0000883056.32529.7d
2. Badawy CR, Jan K, Beck EC, Fleet N, Taylor J, Ford K, et al. Contemporary Principles for Postoperative Rehabilitation and Return to Sport for Athletes Undergoing Anterior Cruciate Ligament Reconstruction. ArthroscopySports Medicine And Rehabilitation [Internet]. 1 de enero de 2022;4(1):e103-13. Disponible en: https://doi.org/10.1016/j.asmr.2021.11.002
3. Mazza D, Viglietta E, Monaco E, Iorio R, Marzilli F, Princi G, et al. Impact of Anterior Cruciate Ligament Injury on European Professional Soccer Players. OrthopaedicJournalOfSports Medicine [Internet]. 1 de febrero de 2022;10(2):23259671221076865. Disponible en: https://doi.org/10.1177/23259671221076865
4. Pinheiro V, Laughlin M, Kent M, Ajgaonkar R, Jones M, Williams A, et al. Poster 337: Impact of an ACL rupture on a professional soccer player's career. Orthopaedic Journal Of Sports Medicine [Internet]. 1 de julio de 2023;11(7_suppl3). Disponible en: https://doi.org/10.1177/2325967123s00304
5. Brzeszczyński F, Forsyth K, McLelland C, McDonald D, Lawson G, Hamilton D. 52 Functional Outcomes and Return to Sport Following Anterior Cruciate Ligament Reconstruction in Recreational Athletes: A Systematic Review. British Journal Of Surgery [Internet]. 19 de agosto de 2022;109(Supplement_6). Disponible en: https://doi.org/10.1093/bjs/znac268.047
6. Provencher M, Mariani P, Haber D, Peebles A, Arner J, Midtgaard K, et al. Paper 28: Early Versus Standard Return to Sport Following ACL Reconstruction. Impact on Volume of Play and Career Logevity in 180 Professional European Soccer Players. Orthopaedic Journal Of

Sports Medicine [Internet]. 1 de julio de 2022;10(7_suppl5). Disponible en: https://doi.org/10.1177/2325967121s00592

7. Manojlovic M, Ninkovic S, Matic R, Versic S, Modric T, Sekulic D, et al. Return to Play and Performance After Anterior Cruciate Ligament Reconstruction in Soccer Players: A Systematic Review of Recent Evidence. Sports Medicine [Internet]. 6 de mayo de 2024;54(8):2097-108. Disponible en: https://doi.org/10.1007/s40279-024-02035-y
8. Kawashima T, Mutsuzaki H, Watanabe A, Ikeda K, Yamanashi Y, Kinugasa T. Impact of Surgical Timing on Functional Outcomes after Anterior Cruciate Ligament Reconstruction. JournalOfClinical Medicine [Internet]. 20 de mayo de 2024;13(10):2994. Disponible en: https://doi.org/10.3390/jcm13102994
9. Fu F, Byrne KJ, Lucidi GA. Editorial Commentary: Outcomes After Anterior Cruciate Ligament Reconstruction Are Defined by Individual Anatomy, Including Both Soft Tissue and Bone Morphology: It's All Important. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 1 de agosto de 2021;37(8):2542-4. Disponible en: https://doi.org/10.1016/j.arthro.2021.04.019
10. Muro S, Kim J, Tsukada S, Akita K. Significance of the broad non-bony attachments of the anterior cruciate ligament on the tibial side. ScientificReports [Internet]. 27 de abril de 2022;12(1):6844. Disponible en: https://doi.org/10.1038/s41598-022-10806-8
11. Fox MA, Zsidai B, Dadoo S, Greiner JJ, Musahl V. Anatomic anterior cruciate ligament reconstruction. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 3 de agosto de 2023;39(9):1968-70. Disponible en: https://doi.org/10.1016/j.arthro.2023.03.004
12. Willinger L, Athwal KK, Holthof S, Imhoff AB, Williams A, Amis AA. Role of the Anterior Cruciate Ligament, Anterolateral Complex, and Lateral Meniscus Posterior Root in Anterolateral Rotatory Knee Instability: A Biomechanical Study. The American Journal Of Sports Medicine [Internet]. 14 de marzo de 2023;51(5):1136-45. Disponible en: https://doi.org/10.1177/03635465231161071
13. Fleming JD, Ritzmann R, Centner C. Effect of an Anterior Cruciate Ligament Rupture on Knee Proprioception Within 2 Years After Conservative and Operative Treatment: A Systematic Review with Meta-Analysis. Sports Medicine [Internet]. 2 de diciembre de 2021;52(5):1091-102. Disponible en: https://doi.org/10.1007/s40279-021-01600-z
14. Beaulieu ML, Ashton-Miller JA, Wojtys EM. Loading mechanisms of the anterior cruciate ligament. SportsBiomechanics [Internet]. 7 de mayo de 2021;22(1):1-29. Disponible en: https://doi.org/10.1080/14763141.2021.1916578
15. Ye B, Liu G, He Z, Xu J, Pan H, Zhu H. Biomechanical mechanisms of anterior cruciate ligament injury in the jerk dip phase of clean and jerk: A case study of an injury event captured on-site. Heliyon [Internet]. 21 de mayo de 2024;10(11):e31390. Disponible en: https://doi.org/10.1016/j.heliyon.2024.e31390
16. Gopinatth V, Casanova FJ, Knapik DM, Mameri ES, Jackson GR, Khan ZA, et al. Consistent Indications and Good Outcomes Despite High Variability in Techniques for Two-Stage Revision

Anterior Cruciate Ligament Reconstruction: A Systematic Review. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 28 de febrero de 2023;39(9):2098-111. Disponible en: https://doi.org/10.1016/j.arthro.2023.02.009

17. Brown CL, Worts PR, Dewig DR, Rolle GA, Ormsbee MJ. Return to Play After an Anterior Cruciate Ligament Reconstruction in the Collegiate Athlete: A Systematic Review Evaluating Return to Play Proportions and Associated Factors. Journal Of Orthopaedic And Sports Physical Therapy [Internet]. 10 de septiembre de 2024;54(10):625-33. Disponible en: https://doi.org/10.2519/jospt.2024.12483
18. Plassche GC, Plancher KD, Brite JE, Briggs KK, Petterson SC. Outcomes Following Bone-patellar Tendon-Bone Anterior Cruciate Ligament Reconstruction In Patients <30 Years: Allograft Vs. Autograft. Medicine &Science In Sports&Exercise [Internet]. 1 de septiembre de 2022;54(9S):437-8. Disponible en: https://doi.org/10.1249/01.mss.0000880552.89301.cb
19. Steiner Q, Walczak B, Watson D. The impact of graft type on functional outcomes following ACL reconstruction: BPTB versus HT autografts. Medicine &Science In Sports&Exercise [Internet]. 1 de septiembre de 2023;55(9S):955-6. Disponible en: http://dx.doi.org/10.1249/01.mss.0000988720.05679.fa
20. Tartibi S, Knapik DM, Pierson SR, Bozorgmehr CK, Touhey DC, Matava MJ, et al. Global Variations in Surgical Techniques for Primary Anterior Cruciate Ligament Reconstruction at Minimum 2-Year Follow-up: A Systematic Review of Randomized Clinical Trials. OrthopaedicJournalOfSports Medicine [Internet]. 1 de septiembre de 2025;13(9):23259671251376574. Disponible en: https://doi.org/10.1177/23259671251376574
21. Wen Z, Zhang H, Yan W, Mohamed SI, Zhao P, Huang X, et al. Anatomical Anterior Cruciate Ligament Reconstruction with Hamstring Tendon Autografts: A Comparative Study of Three Different Techniques. TheJournalOfKneeSurgery [Internet]. 5 de mayo de 2020;34(11):1243-52. Disponible en: https://doi.org/10.1055/s-0040-1702164
22. Nuelle C, Balldin BC, Slone HS. All-Inside anterior cruciate ligament reconstruction. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 1 de agosto de 2022;38(8):2368-9. Disponible en: https://doi.org/10.1016/j.arthro.2022.06.001
23. McDermott ER, Aman ZS, Dekker TJ. Anterior cruciate ligament reconstruction: fixation techniques. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 29 de enero de 2024;40(2):201-3. Disponible en: https://doi.org/10.1016/j.arthro.2023.11.005
24. Dave L. The short graft ACL reconstruction. Orthopaedic Journal Of Sports Medicine [Internet]. 1 de enero de 2023;11(2_suppl). Disponible en: https://doi.org/10.1177/2325967121s00834
25. Ebert JR, Edwards PK, Mayne AIW, Davies PSE, Evans R, Aujla RS, et al. Patients undergoing multiligament knee reconstruction injured during pivoting sports demonstrate similar clinical, functional and return to sport outcomes by 2 years compared with those undergoing anterior cruciate ligament

reconstruction. KneeSurgerySportsTraumatologyArthroscopy [Internet]. 5 de agosto de 2024;33(3):865-77. Disponible en: https://doi.org/10.1002/ksa.12409

26. Benjamin C MA. Editorial Commentary: Anterior Cruciate Ligament Reconstruction Success Must Be Defined Including Patient-Reported Outcome, Functional and Structural Outcome, Avoidance of Early Adverse Events, and Avoidance of Graft Failure. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 31 de marzo de 2022;38(4):1237-8. Disponible en: https://doi.org/10.1016/j.arthro.2021.11.013
27. Oladeji L, Reynolds G, Gonzales H, DeFroda S. Anterior Cruciate Ligament Return to Play: Where Are We Now? TheJournalOfKneeSurgery [Internet]. 17 de julio de 2023;37(08):586-92. Disponible en: http://dx.doi.org/10.1055/a-2130-4909
28. Gill V, Tummala S, Han W, Boddu SP, Verhey JT, Marks L, et al. Athletes Continue to Show Functional Performance Deficits at Return to Sport After Anterior Cruciate Ligament Reconstruction: A Systematic Review. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 21 de enero de 2024;40(8):2309-2321.e2. Disponible en: https://doi.org/10.1016/j.arthro.2023.12.033
29. Song B, Wasserburger J, Till S, Camp C, Levy B, Stuart M, et al. Poster 253: Anterior Cruciate Ligament Reconstruction in 118 Competitive Wrestlers: Outcomes, Reoperations, and Return to Play at 5 years Mean Follow Up. Orthopaedic Journal Of Sports Medicine [Internet]. 1 de julio de 2022;10(7_suppl5). Disponible en: https://doi.org/10.1177/2325967121s00814
30. Lubowitz JH, Brand JC, Rossi MJ. Return-to-Sport Outcomes After Anterior Cruciate Ligament Surgical Treatment May Be Improved by Attention to Modifiable Factors and Consideration of Nonmodifiable Factors. Arthroscopy The Journal Of Arthroscopic And Related Surgery [Internet]. 3 de febrero de 2023;39(3):571-4. Disponible en: https://doi.org/10.1016/j.arthro.2022.12.003
31. Randsborg PH, Cepeda N, Adamec D, Rodeo SA, Ranawat A, Pearle AD. Patient-Reported Outcome, Return to Sport, and Revision Rates 7-9 Years After Anterior Cruciate Ligament Reconstruction: Results From a Cohort of 2042 Patients. The American Journal Of Sports Medicine [Internet]. 18 de enero de 2022;50(2):423-32. Disponible en: https://doi.org/10.1177/03635465211060333
32. Mercurio M, Cofano E, Gasparini G, Galasso O, Familiari F, Sanzo V, et al. Isolated ACL Reconstruction Versus Combined ACL and Anterolateral Ligament Reconstruction: Functional Outcomes, Return to Sport, and Survivorship: An Updated Meta-analysis of Comparative Studies. The American Journal Of Sports Medicine [Internet]. 4 de enero de 2025;53(4):971-80. Disponible en: https://doi.org/10.1177/03635465241251467
33. McAleese T, Welch N, King E, Moffatt L, Keane N, Moran KA, et al. Clinical Outcomes of Anterior Cruciate Ligament Reconstruction in Gaelic Games Players. Orthopaedic Journal Of Sports Medicine [Internet]. 1 de agosto de 2025;13(8):23259671251352207. Disponible en:

https://doi.org/10.1177/23259671251352207

34. Zadehmohammad A, Grillari J, Stevanovic V, Brandl G, Ernstbrunner L, Hoffelner T. Osteoarthritis Progression after ACL Reconstruction Was Significantly Higher Than That of the Healthy Contralateral Knees: Long-Term Follow Up Study of Mean 16.4 Years. JournalOfClinical Medicine [Internet]. 31 de enero de 2022;11(3):775. Disponible en: https://doi.org/10.3390/jcm11030775
35. Grassi A, Pizza N, Al-Zu'bi BBH, Fabbro GD, Lucidi GA, Zaffagnini S. Clinical Outcomes and Osteoarthritis at Very Long-term Follow-up After ACL Reconstruction: A Systematic Review and Meta-analysis. OrthopaedicJournalOfSports Medicine [Internet]. 1 de enero de 2022;10(1):23259671211062238. Disponible en: https://doi.org/10.1177/23259671211062238
36. D'Ambrosi R, Marchetti A, Farinelli L, Meena A, Franco P, Sconfienza LM, et al. The majority of elite and professional athletes return to the preinjury level of activity after ACL reconstruction: A systematic review and meta-analysis. KneeSurgerySportsTraumatologyArthroscopy [Internet]. 31 de agosto de 2025; Disponible en: https://doi.org/10.1002/ksa.70020
37. Pedersen M, Grindem H, Johnson JL, Engebretsen L, Axe MJ, Snyder-Mackler L, et al. Clinical, Functional, and Physical Activity Outcomes 5 Years Following the Treatment Algorithm of the Delaware-Oslo ACL Cohort Study. Journal Of Bone And Joint Surgery [Internet]. 17 de mayo de 2021b;103(16):1473-81. Disponible en: https://doi.org/10.2106/jbjs.20.01731
38. Taylor M, Ihn H, Cushman DM, Bodkin SG. Time of administering return to sport testing following anterior cruciate ligament reconstruction: A systematic review. PhysicalTherapy In Sport [Internet]. 2 de septiembre de 2025;76:1-12. Disponible en: https://doi.org/10.1016/j.ptsp.2025.09.001
39. Muller B, Yabroudi MA, Lynch A, Popchak AJ, Lai C, Van Dijk CN, et al. Return to preinjury sports after anterior cruciate ligament reconstruction is predicted by five independent factors. KneeSurgerySportsTraumatologyArthroscopy [Internet]. 22 de abril de 2021;30(1):84-92. Disponible en: https://doi.org/10.1007/s00167-021-06558-z
40. Beischer S, Senorski EH, Thomeé R. Patients that maintain their pre-injury level of physical activity 3–5 years after ACL reconstruction are, 18 months after surgery, characterised by higher levels of readiness to return to sport. KneeSurgerySportsTraumatologyArthroscopy [Internet]. 19 de noviembre de 2022;31(2):596-607. Disponible en: https://doi.org/10.1007/s00167-022-07230-w
41. Xiao M, Van Niekerk M, Trivedi NN, Hwang CE, Sherman SL, Safran MR, et al. Patients Who Return to Sport After Primary Anterior Cruciate Ligament Reconstruction Have Significantly Higher Psychological Readiness: A Systematic Review and Meta-analysis of 3744 Patients. The American Journal Of Sports Medicine [Internet]. 20 de junio de 2022;51(10):2774-83. Disponible en: https://doi.org/10.1177/03635465221102420