SCOPING REVIEW

Mechanisms and Management of Knee Anterior Cruciate Ligament Injury; A Review

Seyyed Mohsen Hosseininejad, MD; Mohammad Kazem Emami Meybodi, MD; Mehdi Raei, PhD; Alireza Rahimnia, MD

Research performed at Baqiyatallah Hospital, Baqiyatallah University of Medical Sciences, Tehran, Iran

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Abstract

Objectives: This study aimed to clarify the debate on anterior cruciate ligament (ACL) injury management and the selection of patients for surgical or nonsurgical treatment.

Methods: A retrospective, citation-based approach was employed to search for English literature that assessed management options and mechanisms for ACL injuries.

Results: A variety of mechanical and neurocognitive mechanisms are involved in ACL injuries that could be used to develop practical prevention strategies. More precise preoperative clinical, and paraclinical assessments, as well as clarification of available treatment options for patients, would lead to individualized decisions on injury management, and thus to objective and subjective satisfaction. Prioritization of attentive physical therapy rehabilitation plans will also improve treatment outcomes.

Conclusion: A better understanding of the ACL injury/patient characteristics will help to achieve optimal treatment outcomes for each individual and develop targeted and practical prevention strategies.

Level of evidence: II

Keywords: Anterior cruciate ligament, Anterior cruciate ligament reconstruction, Injury management, Injury mechanism, Rehabilitation

Introduction

The most common type of injured ligament in the knee is the anterior cruciate ligament (ACL) as it accounts for 50% or more of all knee injuries.[1] In the United States, 250,000 people sustain ACL injuries each year.[2] The ACL tear is a common injury in sports, and it is the only one of the two cruciate ligaments that is composed of tough fibers that support its repetitive motion. Tearing of these fibers can lead to instability of the knee, particularly anterolateral rotational instability, which can be manifested by giving way during heavy exercises, involving jumping, tackling, or twisting movements (e.g., soccer, field field hockey, and basketball).

Chronic instability is a term used for individuals with old, untreated knee problems who have experienced knee instability during everyday activities. On the other hand, there are individuals with injured ACLs who have minor instability with occasional laxity of the knee.[2-5] these individuals are referred to as adapters, but those who suffer from chronic difficulties are non-adapters. Non-adapters include individuals with inconsistencies in neuromuscular synchronization and other anatomical structures, such as a severely tilted posterior tibia and a narrow intercondylar notch.[5]

Female gender also plays a role, as the literature indicated that the incidence of ACL tears is 2-10 times higher in female sports players, compared to males. Previous studies on passive instability are poor predictors of outcomes after rehabilitation. Given that no specific measurement can define the performance status of an ACL-deficient knee,[2-5] there is a large gray area in the management of individuals with ACL injuries regarding surgical or nonsurgical management. This indicates that there are a number of patients who have undergone ACL reconstruction (ACLR), although a rehabilitation-only plan may have been

Corresponding Author: Alireza Rahimnia, Professor of Pediatric Orthopedics, Department of Orthopedics, School of Medicine, Ayatollah Taleghani Hospital, Shahid Beheshti University of Medical Sciences/ Baqqiatallah University of Medical Sciences, Tehran, Iran

Email: alireza_rahimnia@yahoo.com

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sufficient; this could lead to bias in the studies that report the outcomes of ACLR in amateur players. Therefore, it is necessary to closely examine the patients before deciding on surgical or non-surgical treatment.[5,6] This review aimed to describe different mechanisms and treatment strategies for ACL injuries to help clinicians select the right treatment for their patients and make shared treatment decisions with the central goal of optimizing the functions of patients.

Materials and Methods

A retrospective, citation-based approach was employed to search for English-language literature that assessed or used different management options and also proposed mechanisms for ACL injuries. The main sources were peer-reviewed published articles searched in PubMed, Web of Science, Science Direct, and Google Scholar databases using the following keywords: "Anterior cruciate ligament injuries, Conservative treatment, Patient selection, Treatment outcome, Anterior cruciate ligament reconstruction, Bias, Injury management, Injury mechanism, Rehabilitation". No systematic search strategy was applied, and the authors independently reviewed and reflected on the literature.

Results

Mechanisms

The ACL can be injured or torn in different mechanisms, namely non-contact, contact-direct, and contact-indirect mechanisms. Reports indicate that 88% of ACL injuries followed non-contact knee injuries.[7] Nevertheless, contact trauma is as important as non-contact mechanisms, emphasizing the mechanical disruption. Non-contact injuries occur when an extreme internal body force is generated without external forces acting to cause the tear. The most common risk situations for an ACL tear are landings, presses, an uncooperative dynamic body and regaining balance after a kick,[8,9] pivot,[10,11] cut-and-plant maneuver,[12] tackle,[8,9] deceleration,[10,11] and also vehicle accidents.[13] However, the most common mechanism is the sudden pivoting of the knee in athletic situations, such as soccer, field hockey, and basketball.[7,14-16]

The same injury mechanisms seen in sports also occur in the military, where the activities are very intense.[17-19] Video analysis has revealed that most ACL injuries are due to prior contact, slight hip and knee flexion, and heel strike leading to valgus failure with neutral rotation of the knee.[20,21] Axial constriction and agitation just prior to the injury, as well as unexpected disruption of the body, also play a role[14]. Perturbation and excitement can disrupt the normal neuromuscular status, resulting in an unsteady position of the leg on the ground.[22]

Sudden eccentric contraction of the quadriceps muscle during abduction of the knee (such as occurs during pivoting) can increase the constricting force at the joint and actually depress the axial injury limit.[14,22,23] Studies on cadavers also support the idea that axial constricting force is the key factor in non-contact ACL injuries.[22,23] It should be noted that female sports players have remarkable similarities with male sports players in terms of ACL injury patterns,[7,24] but are at higher risk of ACL injury, compared to male sports players due to dissimilarities in physical preparation, muscle strength, and neuromuscular action.[25]

Reduced hamstring strength relative to quadriceps has been implicated as a potential mechanism for increased lower limb injuries.[26] Research has shown that female athletes, who sustained an ACL injury following a strength test, had a combination of reduced strength in the hamstring, but not in the quadriceps, compared to male athletes. In contrast, female athletes, who did not sustain an ACL injury, had reduced quadriceps strength and similar hamstring strength, compared to matched male athletes.[26,27] This understanding of the factors and mechanisms associated with ACL injuries could reduce the incidence of ACL injuries and help to develop targeted injury prevention protocols.[18,21,23]

Surgical treatment

There is widespread agreement that ACL surgery in professional athletes of both genders can pave the way to return to previous athletic levels. Moreover, prepubertal and adolescent knees do not appear to heal perfectly after ACL rupture,[28] if not operated; therefore, these young people and people with a coexisting repairable meniscal injury may benefit from ACLR.[5,28,29]

In general, the most commonly performed procedure is the arthroscopic reconstruction of a torn ACL by anatomical placement of grafts. However, various autologous replacement grafts are available, including grafts of the patellar tendon (BPTB), quadriceps tendon and hamstring tendon (semitendinosus and/or gracilis), as well as allografts and synthetic grafts. The debate about which graft is the best choice is still ongoing. However, a higher rate of revision surgery has been reported after hamstring grafts for primary ACLR, compared to BPTB grafts, especially in young sports players. Ideally, graft selection for ACLR should be based on the age, anatomy, requirements, and expectations of the patient. The physicians should be familiar with all the existing ACLR graft options and clinical outcomes in order to achieve an optimal treatment outcome.[30-32]

In recreational athletes, it is not clear whether an interval in performing surgery is a disadvantage. There is limited evidence on whether surgical or non-surgical treatment leads to better outcomes in this population. It should be noted that many people do well despite a damaged ACL. However, top performers are immediate candidates for surgical intervention. Clearly, restoration of normal knee performance after an ACL rupture requires surgery to accurately reproduce the normal ligament.[5,33]

The ACL has functions that play an essential role in the maintenance of knee performance and stability. Therefore, reconstruction of the ruptured ACL is necessary to prevent the inexorable decline in knee function. Even after ACL reconstruction, the normal kinematics of the knee joint are not restored and degenerative changes can occur in the long term, especially in young and active individuals. Hence, it is important to identify the knees that will benefit from reconstruction. Apart from professional sports players and other smaller at-risk populations, there is no absolute agreement on the patients whose knees need or do not need reconstruction (e.g. adapter vs. non-adapter patients). However, the formulation of strategies to differentiate between adapters and non-adapters could answer the question.[5,33,34]

Another important issue is the concept of isometry. This idea emerged after the introduction of the term "screw home", which refers to the plane of movement of the knee during flexion and extension. The cooperation between the posterior cruciate ligament (PCL) and the ACL during knee movement was associated with a fixed, four-link joint structure in which the PCL and ACL act as isometric constructs. This theory clarified the isometric replacement of the graft during ACLR. However, dynamic magnetic resonance imaging (MRI) studies have clearly demonstrated that the PCL and ACL wrap around each other in the knee screw home mechanism, resulting in the ACL/PCL constructs shortening the least during terminal knee extension. Accordingly, the ACL is not an isometric construct. The theory of isometric positioning has been replaced by the so-called anatomical positioning.[5,35,36]

Furthermore, it has been assumed that the autologous graft transforms into the biological nature of the ligament over time through the process of ligamentization after implantation. The graft has been shown to undergo an early phase of vascularization with rapid attenuation, followed by cellular development and maturation, which is completed approximately six months after graft placement. Evidence for this progression comes primarily from human histopathologic specimens and animal studies.

Most reports of ligamentization of implants in humans indicate that complete restoration of the mechanical and biological properties of the original ACL does not appear to be successful.[37-39] an important study using contrast-enhanced MRI after ACLR in military personnel clearly showed that the avascularity of the graft was preserved for up to two years postoperatively.[40,41]

Furthermore, electron microscopy has shown that the fine structures of the graft do not match the natural ligament after maturation. However, there is a new technique called bridge-enhanced ACL restoration implant (BEAR), in which an autologous blood-inoculated implant is used to form a bridge between the torn ends of an ACL. The collagen implant helps strengthen the ligament and increases the strength of the ligament,[42] which can help surgeons create a more natural ligament.

In addition, the concept of anatomic positioning of the ACL suggests that the tunnels be placed at the anatomic femoral and tibial origin of the ACL. For the reconstruction of a single ligament, the optional position is in the center of the femoral and tibial origin. The tibial origin naturally extends anteriorly and is larger than the femoral origin. Therefore, special care must be taken when planning the tibial tunnel to ensure that it is not too far anterior, as the implant could become trapped in the intercondylar notch during knee extension.[43-45]

In addition, tunnels placed at the center of the anatomic origin of the femoral ACL insertion have been shown to be more prone to failure, compared to the tunnels placed off-center. Recent morphology studies of the ACL have shown that the ACL is a ribbon-like construct and not a conical cylinder as described in the classic literature. Therefore, it may be necessary to reconsider the localization techniques used in ACLR.[46]

It is evident that current anatomic placement techniques in ACLR would not restore the original kinematics of the knee. Point-to-point fixation of the fiber bundles extending from their proper anatomic origins at the femoral and tibial portions and allowing consecutive stretching of the ACL through flexion and extension is not achieved. Since the ligament is inherently complex, current ACLR methods, whether isometric or anatomic, are unlikely to accurately reflect its true nature and thus its function.[5,47]

However, surgeons are now increasingly performing ACL reconstructions with additional anterolateral tenodesis. Reinforcement of the lateral structures of the knee provides further rotational stability and protection for the graft. This is particularly beneficial in high-risk patients, e.g. patients with excessive laxity or malpositioning, younger patients, or when the surgery is a revision of the ACLR.[48]

Nevertheless, there are some studies that may be underpowered and have weak study designs that suggest better outcomes with ACLR+anterolateral tenodesis. A recent review reported that ACLR+anterolateral tenodesis significantly improved the rate of graft failure and return to sport, compared to ACLR in isolation.[48,49] Another problem is that ACLR is not always reproducible. Even among experienced surgeons, outcome analyses and postoperative radiographs show different positions for the tunnels, especially the femoral tunnels.[47,50]

Conservative management

Physicians agree that rehabilitation after an ACL injury is essential both before and after surgery, as well as for individuals who prefer non-surgical treatment. The details of rehabilitation may differ, but the overall approach is similar. The use of blood flow restriction, neuromuscular electrical stimulation, early lower limb training, neuromuscular and proprioceptive exercises, and psychosocial support have recently become popular modalities in ACLR rehabilitation.[51,52]

In the category of adapters, where rehabilitation may preclude the need for surgery, the challenge is the appropriate intensity of rehabilitation and patient adherence to the plan. The psychosocial status and expectations of the patient should be carefully considered. The role of the sports physiotherapist in the management of knees with ACL tears should be given more importance than is currently the case.[53,54] The role of non-surgical and surgical management in the treatment of injured ACLs was recognized in the United States several years ago by the major developers of ACL injury treatment.

Noyes et al. defined that the “rule of thirds” is applied; accordingly, after an ACL injury, one-third of cases will require surgery, one-third of cases will require rehabilitation without ACLR, and the remaining one third will be asymptomatic and not require surgery.[55] There is no doubt that each of these groups exists; however, the challenge is to distinguish between adapters and non-adapters and to categorize the cases into actual groups.[5,56]

Many studies have reported acceptable to excellent outcomes after ACLR, but even the best studies have shown

that outcomes are not favorable in 10-15% of the cases. A recent study found that 86% of hamstring grafts used in ACLR generally survived 20 years. However, in adolescents, this survival rate was 61%, dropping to 22% in those with a posterior tibial slope of 12° or more.[5,57,58]

Previous reports have noted that return to sport is a measure of effective treatment; however, they have not specified the level of sport. Published studies have also shown a growing opposition between authors who are generally optimistic about the efficacy of ACLR and those who question this positive view based on recent accurate and well-organized data.[15,59] A recent review also questioned whether ACLR has superior efficacy, compared to rehabilitation.[60]

Previously, one of the rationales for early ACLR was the belief that the ACL works synergistically with the other stabilizing components of the knee joint, such as the meniscus and other ligaments. If the ACL is torn, this could compromise its crucial role in interacting with other components of the knee. Constant stress on knees with ACL defects leads to joint incompetence and osteoarthritis. Although this is possible, it may not always be the case, especially if the tear is diagnosed acutely.

Early diagnosis allows patients to undergo rehabilitation and adapt their physical activities. Accordingly, even if patients have joint laxity, they will not feel instability as the ACL is only loaded up to 20% of its maximum during daily activities.[61] Therefore, it is important to diagnose the injury quickly. An ACLR should only be considered if the affected person needs to return to high levels of sporting performance.[5]

Recently, studies on the outcomes and principles of ACL injury have gained prominence in the literature. Despite this extensive literature base, it is unexpected that no logical consensus has been reached on the treatment of the cruciate ligament-injured knee, except in athletes.[5,62]

Previous studies addressing evidence in sports medicine have reported a need for large-scale, high-level evidence-based, multiply randomized trials. The authors discuss that the evidence base for the performance of orthopedic surgery is insufficient, compared to other medical fields, with only one-fifth of procedures having at least one randomized trial with low bias, indicating that surgery is preferable to conservative interventions.[5,63]

Most studies on the mid-term outcomes of ACLR in terms of knee function indicate that moderate functional stability was achieved with the recurrence of partial laxity, mainly rotational laxity. Knee range of motion and functional recovery were also reported to be acceptable. However, it was found that only 50% of these patients were able to regain their pre-injury activity level. The re-injury rate with a previously reconstructed ACL was up to six times higher than the rate of the original ACL tear. Moreover, female sports players with a history of ACL tear have a higher risk of re-injury. Besides, injury to the opposite knee also has a higher risk. General laxity of the joint, especially in conjunction with hyperextension, is a predisposing factor for re-injury. The ACLR would not restore the original knee kinematics, proprioceptive sensation, and ultra-nature of the ACL. There are a number of medium and long-term reports of joint degeneration in ACL-reconstructed knees, especially when returning to high-performance sports. Therefore, long-term maintenance of the health of the intra-articular environment after ACL reconstruction is discussed as well as the achievement of satisfactory criteria for patients and surgeons in terms of surgical outcome.[5,64]

Associated meniscal and cartilage lesions affect outcomes after ACL injuries. As previously mentioned, human proprioceptive adaptations and variable anatomic morphology may partially explain the conundrum of adapters and non-adapters. Bony contusions of the femoral condyles, often seen on MRI after ACL injuries, may lead to the development of cartilage lesions. This indicates that the ACL injury is probably not an isolated case.[5,54]

Discussion

The ACL injuries occur mainly in the young population usually in sports in Western societies. The data gathered from other developed countries suggests that its incidence in the UK results in nearly 200 new cases per year. A study performed in the United States found that the highest incidence of injury occurred at the age ranges of 19-25 and 14-18 years old in males and females, respectively.[65]

Physicians continue to see chronic ACL defects, either since the lesion was previously overlooked in trauma hospitals or since it recovered from an acute initial injury in which it was undiagnosed and individuals continued their athletic activities; serial procedures could lead to recurrent events of functional instability and consequent knee deterioration. There seems to be a necessity for a well-directed referral path through which acute knee injuries identified in the emergency department are directed to a specialized center where detailed evaluation and treatment are performed.[66,67]

Previously, the literature divided the mechanisms of ACL injuries biomechanically into non-contact and contact mechanisms, with a focus on mechanics. However, more recent reports have also emphasized neurocognitive aspects of ACL injury occurrence. Since sportspersons must meet synchronized cognitive demands on the playing field, any imbalance in cognitive coordination may contribute to limb misalignment, increasing the risk of ACL injury.[14] Knowledge of the various mechanisms of ACL injuries and predisposing factors also suggests that targeted prevention strategies would be most successful.[68]

Reaching a consensus on the most appropriate treatment for cases with a torn ACL is complicated by many conflicting reports. The satisfactory reports of ACLR in professional sportspersons presented in a meta-analysis contrast with other reports showing poorer outcomes in this group.[69] Other reports may have been biased due to poor methods. Moreover, observer bias may justify up to 15% of the satisfactory results presented by the participating team. For this reason, these reports should be presented by independent observers. Recognition bias may also occur when successful treatment is reported based on different knee assessment scales. However, some standardized scales,

such as Tegner, Lysholm, and the Injury and Osteoarthritis Outcome Score have recently been introduced.

Susceptibility to bias arises when results are pooled for individuals with fundamentally different prognoses, e.g., adolescent sportspersons versus middle-aged recreational skiers. Performance bias occurs when authors combine results from populations in which different surgical methods and rehabilitation protocols were used. Transfer bias is possible when an undetermined number of cases are overlooked at follow-up, giving an inaccurate impression of failure or success in the existing population. Last but not least, confirmation bias is triggered by the large number of available studies on ACL, allowing authors to select reports that support predetermined concepts. [5,70,71]

Clarification of the natural history of ACL injuries prevents patients from mistakenly opting for surgery, as shared decision-making is key to successful treatment; attentive rehabilitation ensures excellent outcomes. The realization that conservative treatment can be superior to surgery and does not aggravate the process of knee osteoarthritis is a guide for patients when choosing a treatment method.

In the case of surgery, individualized graft selection is important. Afterward, strength and function should be the goal of rehabilitation. A rapid increase in training load and a return to sport earlier than nine months should be avoided. The content of rehabilitation should be the same for those who choose the conservative route, even if they would return to sport sooner. All patients should be educated about the relationship between injury risk and training load and recognize that a home exercise plan is just as important as vigilant training under the guidance of a physical therapist.[30,54,72]

Furthermore, there is no clear link between the interpretation of results by the surgeon and the patient. The presence of partial laxity is not associated with lower postoperative patient satisfaction. Conversely, physicians may not consider the presence of any degree of laxity as an acceptable outcome. There may be a strong correlation between the recurrence of even minor laxity and the ability of a person to return to exercise. Some authors have pointed out the need to consider factors that determine patient satisfaction and their relationship with an objective assessment of knee laxity.[54,73]

Although evidence-based practice is called for in medicine in general, its implementation in the case of ACL injuries causes difficulties. This is almost strongly related to the above-mentioned problems. In addition, in healthcare systems with limited resources, financial support for subspecialty clinics may not be a priority. To create a comprehensive evidence base, data should be collected from different centers over a long period of time to account for the possibility of performance bias.[74,75] Randomized controlled trials are difficult to establish but have the potential to answer important questions for the long-term management of ACL injuries.[5,76]

Conclusion

Cognitive aspects have been added to the biomechanical theory of ACL injury mechanisms. Balanced, synchronized neuromuscular coordination is required for sportspersons who must consider multiple external stimuli and decide on the correct action. Any delayed or faulty coordination can lead to an unbalanced neuromuscular process, malalignment of the knee, and subsequent ACL injury. A better reorganization of the mechanisms involved will lead to targeted and, therefore, feasible prevention plans.[8,14]

Current surgical performance may not result in an original anatomic ACLR as there are problems with the fixation of the bone tunnel. The location of the tunnels and the various devices used to stabilize the grafts do not contribute to accurate anatomic positioning that simulates the natural alignment and biomechanics of the ligament.[77,78] The current performance of ACLR may have reached an impasse, despite the ongoing debate about the relative values of single- or double-bundle reconstruction of the hamstring tendon.[79,80] Recently, the ACL has been reported to have a ribbon-like anatomy.[30,81]

The existence of anterior rotational instability is not an absolute indication of ACLR. Johnson et al. previously stated that there are no clear indications for surgical reconstruction. This is, to date, still true. However, the above-mentioned relative indications suggest that young professional athletes may benefit from ACLR.[82] It was found that 60% of ACLRs were most likely not necessary.[83] A randomized controlled trial that compared the surgical and non-surgical management outcomes found that all cases with ACL tears that did not undergo surgery were successfully treated two years after injury.[84] Individuals with an ACL injury undergoing ACLR should be aware that there is no absolute evidence about the ability of ACLR to deliver the original proprioception or kinematics to their knee. The natural anatomy of the ligament will not be reestablished, and there will be a risk of long-term degenerative changes in the reconstructed joint, particularly in young, professional, active individuals.[5,84,85]

In this review, it was emphasized that early recognition of the torn ACL is necessary. Moreover, a perfect administrative clinical procedure is required to separate adapters from non-adapters. If ACLR is the choice, a focused preoperative evaluation is required, including relevant radiographs and MRI, laxity test, evaluation of neuromuscular function and knee anatomy, and consideration of the gender of the patient. The ACLR should be maintained in patients with a combined ACL and meniscal/cartilage lesion or in professional sports players.

It should be kept in mind that ACLR alone cannot prevent future risk of degenerative changes and re-injury to the operated knee. The natural history of the injury and the details of surgical and conservative management should be communicated to the affected person to help them fully engage in the treatment, leading to shared decision-making, and therefore, optimizing treatment and outcomes. Updated attentive and targeted rehabilitation should be provided by sports physical therapists for individuals with an injured knee. A better understanding of the patient/injury-related issues will help to achieve optimal treatment outcomes and develop targeted and practical prevention strategies.

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Seyyed Mohsen Hosseininejad MD [1,2]
Mohammad Kazem Emami Meybodi MD [2]
Mehdi Raei PhD [3,4]
Alireza Rahimnia MD [5,2]

1 School of Medicine, Orthopedic Department, Golestan University of Medical Sciences, Gorgan, Iran

2 School of Medicine, Baqiyatallah University of Medical Sciences, Tehran, Iran

3 Health Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran

4 Department of Epidemiology and Biostatistics, Faculty of Health, Baqiyatallah University, Tehran, Iran

5 Department of Orthopedics, School of Medicine, Ayatollah Taleghani Hospital, Shahid Beheshti University of Medical Sciences, , Tehran, Iran

References

1. Risberg MA, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? Physical Therapy in Sport. 2004; 5(3):125-145. doi:10.1016/j.ptsp.2004.02.003.
2. MacLeod TD, Snyder-Mackler L, Buchanan TS. Differences in neuromuscular control and quadriceps morphology between potential copers and noncopers following anterior cruciate ligament injury. J Orthop Sports Phys Ther. 2014; 44(2):76-84. doi:10.2519/jospt.2014.4876.
3. Duthon V, Barea C, Abrassart S, Fasel J, Fritschy D, Ménétrey J. Anatomy of the anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc. 2006; 14:204-213. doi:10.1007/s00167-005-0679-9.
4. Grindem H, Wellsandt E, Failla M, Snyder-Mackler L, Risberg MA. Anterior cruciate ligament Injury—who succeeds without reconstructive surgery? The Delaware-Oslo ACL cohort study. Orthop J Sports Med. 2018; 6(5):2325967118774255. doi:10.1177/2325967118774255.
5. Mowbray MAS, Ireland J. Personal and narrative review of the current management of the injured anterior cruciate ligament of the knee in the UK with reference to surgical treatment versus rehabilitation. BMJ Open Sport Exerc Med. 2022; 8(3):e001410. doi: 10.1136/bmjsem-2022-001410.
6. Filbay SR, Grindem H. Evidence-based recommendations for the management of anterior cruciate ligament (ACL) rupture. Best Pract Res Clin Rheumatol. 2019; 33(1):33-47. doi:10.1016/j.berh.2019.01.018.
7. Lucarno S, Zago M, Buckthorpe M, et al. Systematic video analysis of anterior cruciate ligament injuries in professional female soccer players. Am J Sports Med. 2021; 49(7):1794-1802. doi: 10.1177/03635465211008169.
8. Della Villa F, Buckthorpe M, Grassi A, et al. Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. Br J Sports Med. 2020; 54(23):1423-1432. doi: 10.1136/bjsports-2019-101247.
9. Wetters N, Weber AE, Wuerz TH, Schub DL, Mandelbaum BR. Mechanism of injury and risk factors for anterior cruciate ligament injury. Operative Techniques in Sports Medicine. 2016; 24(1):2-6.
10. Shimokochi Y, Shultz SJ. Mechanisms of noncontact anterior cruciate ligament injury. J Athl Train. 2008; 43(4):396-408. doi: 10.4085/1062-6050-43.4.396.
11. Schick S, Cantrell CK, Young B, et al. The mechanism of anterior cruciate ligament injuries in the National Football League: a systematic video review. Cureus. 2023; 15(1):e34291. doi: 10.7759/cureus.34291.
12. Dix C, Arundale A, Silvers-Granelli H, Marmon A, Zarzycki R, Snyder-Mackler L. Biomechanical measures during two sport-specific tasks differentiate between soccer players who go on to anterior cruciate ligament injury and those who do not: a prospective cohort analysis. Int J Sports Phys Ther. 2020; 15(6):928. doi: 10.26603/ijspt20200928.
13. Musahl V, Karlsson J. Anterior cruciate ligament tear. N Engl J Med. 2019; 380(24):2341-2348. doi: 10.1056/NEJMcp1805931.
14. Gokeler A, Benjaminse A, Della Villa F, Tosarelli F, Verhagen E, Baumeister J. Anterior cruciate ligament injury mechanisms through a neurocognition lens: implications for injury screening. BMJ Open Sport Exerc Med. 2021; 7(2):e001091. doi:10.1136/bmjsem-2021-001091.
15. Rodriguez K, Soni M, Joshi PK, et al. Anterior cruciate ligament injury: conservative versus surgical treatment. Cureus. 2021; 13(12).doi:10.7759/cureus.20206.
16. Rigg JD, Perera NKP, Toohey LA, Cooke J, Hughes D. Anterior cruciate ligament injury occurrence, return to sport and subsequent injury in the Australian High Performance Sports System: A 5-year retrospective analysis. Physical Therapy in Sport. 2023; 64:140-146.
17. Ahn J, Choi B, Lee YS, Lee KW, Lee JW, Lee BK. The mechanism

and cause of anterior cruciate ligament tear in the Korean military environment. Knee Surg Relat Res. 2019; 31:1-5. doi:10.1186/s43019-019-0015-1.
18. Schram B, Orr R, Pope R. A profile of knee injuries suffered by Australian army reserve soldiers. Int J Environ Res Public Health. 2019; 16(1):12. doi:10.3390/ijerph16010012.
19. Hosseininejad S-M, Emami Meybodi MK, Raei M, Rahimnia A. Prevalence and mechanisms of anterior cruciate ligament tears in military personnel: A cross-sectional study in Iran. PLoS One. 2024; 19(6):e0303326. doi: 10.1371/journal.pone.0303326.
20. Schick S, Cantrell CK, Young B, et al. The mechanism of anterior cruciate ligament injuries in the National Football League: a systematic video review. Cureus. 2023; 15(1).doi:10.7759/cureus.34291.
21. Haddara R, Harandi VJ, Lee PVS. Anterior cruciate ligament agonist and antagonist muscle force differences between males and females during perturbed walking. J Biomech. 2020; 110:109971. doi:10.1016/j.jbiomech.2020.109971.
22. Wall SJ, Rose DM, Sutter EG, Belkoff SM, Boden BP. The role of axial compressive and quadriceps forces in noncontact anterior cruciate ligament injury: a cadaveric study. Am J Sports Med. 2012; 40(3):568-573. doi:10.1177/0363546511430204.
23. Boden BP, Sheehan FT. Mechanism of non-contact ACL injury: OREF Clinical Research Award 2021. J Orthop Res. 2022; 40(3):531-540. doi:10.1002/jor.25257.
24. Faude O, Junge A, Kindermann W, Dvorak J. Risk factors for injuries in elite female soccer players. Br J Sports Med. 2006; 40(9):785-790. doi:10.1136/bjsm.2006.027540.
25. Delincé P, Ghafil D. Anterior cruciate ligament tears: conservative or surgical treatment? A critical review of the literature. Knee Surg Sports Traumatol Arthrosc. 2012; 20:48-61. doi:10.1007/s00167-011-1614-x.
26. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. J Athl Train. 2004; 39(4):352.
27. Myer GD, Ford KR, Foss KDB, Liu C, Nick TG, Hewett TE. The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. Clin J Sport Med. 2009; 19(1):3-8. doi: 10.1097/JSM.0b013e318190bddb.
28. Wojtys EM, Brower AM. Anterior cruciate ligament injuries in the prepubescent and adolescent athlete: clinical and research considerations. J Athl Train. 2010; 45(5):509-512. doi: 10.4085/1062-6050-45.5.509.
29. Tuca M, Valderrama I, Eriksson K, Tapasvi S. Current trends in anterior cruciate ligament surgery. A worldwide benchmark study. J ISAKOS. 2023; 8(1):2-10. doi:10.1016/j.jisako.2022.08.009.
30. Buerba RA, Boden SA, Lesniak B. Graft selection in contemporary anterior cruciate ligament reconstruction. JAAOS Global Research & Reviews. 2021; 5(10) doi:10.1016/j.eats.2023.02.022.
31. Snaebjörnsson T, Hamrin-Senorski E, Svantesson E, et al. Graft diameter and graft type as predictors of anterior cruciate ligament revision: a cohort study including 18,425 patients from the Swedish and Norwegian National Knee Ligament Registries. J Bone Joint Surg Am. 2019; 101(20):1812-1820. doi:10.2106/JBJS.18.01467.
32. Todor A. Graft Choice in Anterior Cruciate Ligament Reconstruction.in: Arthroscopic Surgery - New Perspectives. 1th ed. Stetson WB,eds. IntechOpen ;2024.
33. Saueressig T, Braun T, Steglich N, et al. Primary surgery versus primary rehabilitation for treating anterior cruciate ligament injuries: a living systematic review and meta-analysis. Br J Sports Med. 2022; 56(21):1241-1251. doi:10.1136/bjsports-2021-105359.
34. Cheung EC, DiLallo M, Feeley BT, Lansdown DA. Osteoarthritis and ACL Reconstruction-Myths and Risks. Curr Rev Musculoskelet Med. 2020; 13:115-122. doi:10.1007/s12178-019-09596-w.
35. Etoundi AC, Semasinghe CL, Agrawal S, Dobner A, Jafari A. Bio-inspired knee joint: trends in the hardware systems development. Front Robot AI. 2021; 8:613574. doi:10.3389/frobt.2021.613574.
36. Guenoun D, Vaccaro J, Le Corroller T, et al. A dynamic study of the anterior cruciate ligament of the knee using an open MRI. Surg Radiol Anat. 2017; 39(3):307-314. doi: 10.1007/s00276-016-1730-x.
37. Pauzenberger L, Syré S, Schurz M. "Ligamentization" in hamstring tendon grafts after anterior cruciate ligament reconstruction: a systematic review of the literature and a glimpse into the future. Arthroscopy.2013; 29(10):1712-1721. doi:10.1016/j.arthro.2013.05.009.
38. Claes S, Verdonk P, Forsyth R, Bellemans J. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. Am J Sports Med. 2011; 39(11):2476-2483. doi:10.1177/0363546511402662.
39. Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligamentization after cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2008; 16:834-842. doi:10.1007/s00167-008-0560-8.
40. Howell SM, Clark JA, Blasier RD. Serial magnetic resonance imaging of hamstring anterior cruciate ligament autografts during the first year of implantation: a preliminary study. Am J Sports Med. 1991; 19(1):42-47. doi:10.1177/036354659101900107.
41. Liu S, Li H, Tao H, Sun Y, Chen S, Chen J. A randomized clinical trial to evaluate attached hamstring anterior cruciate ligament graft maturity with magnetic resonance imaging. Am J Sports Med. 2018; 46(5):1143-1149. doi:10.1177/0363546517752918.
42. Murray MM, Kalish LA, Fleming BC, et al. Bridge-enhanced anterior cruciate ligament repair: two-year results of a first-in-human study. Orthop J Sports Med. 2019; 7(3):2325967118824356. doi:10.1177/2325967118824356.
43. Bedi A, Maak T, Musahl V, et al. Effect of tibial tunnel position on stability of the knee after anterior cruciate ligament reconstruction: is the tibial tunnel position most important? The Am J Sports Med. 2011; 39(2):366-373. doi:10.1177/0363546510388157.
44. Samitier G, Marcano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. Arch Bone Jt Surg. 2015; 3(4):220.
45. Rahnemai-Azar AA, Sabzevari S, Irarrázaval S, Chao T, Fu FH. Anatomical individualized ACL reconstruction. Arch Bone Jt Surg. 2016; 4(4):291.

46. Śmigielski R, Zdanowicz U, Drwięga M, Ciszek B, Ciszkowska-Łysoń B, Siebold R. Ribbon like appearance of the midsubstance fibres of the anterior cruciate ligament close to its femoral insertion site: a cadaveric study including 111 knees. Knee Surg Sports Traumatol Arthrosc. 2015; 23:3143-3150. doi:10.1007/s00167-014-3146-7.
47. Rayan F, Nanjayan SK, Quah C, Ramoutar D, Konan S, Haddad FS. Review of evolution of tunnel position in anterior cruciate ligament reconstruction. World J Orthop. 2015; 6(2):252. doi:10.5312/wjo.v6.i2.252.
48. Meynard P, Pelet H, Angelliaume A, et al. ACL reconstruction with lateral extra-articular tenodesis using a continuous graft: 10-year outcomes of 50 cases. Orthop Traumatol Surg Res. 2020; 106(5):929-935. doi:10.1016/j.otsr.2020.04.007.
49. Sonnery-Cottet B, Barbosa NC, Vieira TD, Saithna A. Clinical outcomes of extra-articular tenodesis/anterolateral reconstruction in the ACL injured knee. Knee Surg Sports Traumatol Arthrosc. 2018; 26:596-604. doi:10.1007/s00167-017-4596-5.
50. Topliss C, Webb J. An audit of tunnel position in anterior cruciate ligament reconstruction. Knee. 2001; 8(1):59-63. doi:10.1016/s0968-0160(01)00067-9.
51. Andrade R, Pereira R, van Cingel R, Staal JB, Espregueira-Mendes J. How should clinicians rehabilitate patients after ACL reconstruction? A systematic review of clinical practice guidelines (CPGs) with a focus on quality appraisal (AGREE II). Br J Sports Med. 2020; 54(9):512-519. doi:10.1136/bjsports-2018-100310.
52. Jenkins SM, Guzman A, Gardner BB, et al. Rehabilitation after anterior cruciate ligament injury: Review of current literature and recommendations. Curr Rev Musculoskelet Med. 2022; 15(3):170-179. doi:10.1007/s12178-022-09752-9.
53. Culvenor AG, Girdwood MA, Juhl CB, et al. Rehabilitation after anterior cruciate ligament and meniscal injuries: a best-evidence synthesis of systematic reviews for the OPTIKNEE consensus. Br J Sports Med. 2022; 56(24):1445-1453. doi:10.1136/bjsports-2022-105495.
54. Petersen W, Häner M, Guenther D, et al. Management after acute injury of the anterior cruciate ligament (ACL), part 2: management of the ACL-injured patient. Knee Surg Sports Traumatol Arthrosc. 2023; 31(5):1675-1689. doi:10.1007/s00167-022-07260-4.
55. Noyes FR, Mooar P, Matthews D, Butler D. The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. J Bone Joint Surg Am. 1983; 65(2):154-162. doi:10.2106/00004623-198365020-00003.
56. Button K, van Deursen R, Price P. Classification of functional recovery of anterior cruciate ligament copers, non-copers, and adapters. Br J Sports Med. 2006; 40(10):853-859. doi:10.1136/bjsm.2006.028258.
57. Group MK. 10 Year Outcomes and Risk Factors after ACL Reconstruction: A MOON Longitudinal Prospective Cohort Study. Am J Sports Med. 2018; 46(4):815. doi:10.1177/0363546517749850.
58. Costa GG, Perelli S, Grassi A, Russo A, Zaffagnini S, Monllau JC. Minimizing the risk of graft failure after anterior cruciate ligament reconstruction in athletes. A narrative review of the current evidence. Journal of Experimental Orthopaedics. 2022; 9(1):26. doi:Minimizing the risk of graft failure after anterior cruciate ligament reconstruction in athletes. A narrative review of the current evidence. J Exp Orthop.2022; 9(1):26. doi: 10.1186/s40634-022-00461-3.
59. DeFazio MW, Curry EJ, Gustin MJ, et al. Return to sport after ACL reconstruction with a BTB versus hamstring tendon autograft: a systematic review and meta-analysis. Orthop J Sports Med. 2020; 8(12):2325967120964919. doi:10.1177/2325967120964919.
60. Blom AW, Donovan RL, Beswick AD, Whitehouse MR, Kunutsor SK. Common elective orthopaedic procedures and their clinical effectiveness: umbrella review of level 1 evidence. BMJ. 2021:374:n1511.doi:10.1136/bmj.n1511.
61. McGinty JB, Burkhart SS, eds. Operative arthroscopy. 3st ed. Lippincott Williams & Wilkins; 2003.
62. Giummarra M, Vocale L, King M. Efficacy of non-surgical management and functional outcomes of partial ACL tears. A systematic review of randomised trials. BMC Musculoskelet Disord. 2022; 23(1):332. doi:10.1186/s12891-022-05278-w.
63. Chellamuthu G, Muthu S, Damodaran UK, Rangabashyam R. "Only 50% of randomized trials have high level of confidence in arthroscopy and sports medicine"—a spin-based assessment. Knee Surg Sports Traumatol Arthrosc. 2021; 29(9):2789-2798. doi:10.1007/s00167-021-06614-8.
64. Webster KE. Return to sport and reinjury rates in elite female athletes after anterior cruciate ligament rupture. Sports Med. 2021; 51(4):653-660. doi:10.1007/s40279-020-01404-7.
65. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. Am J Sports Med. 2016; 44(6):1502-1507. doi:10.1177/0363546516629944.
66. Ball S, Haddad FS. The impact of an acute knee clinic. Ann R Coll Surg Engl. 2010; 92(8):685-688. doi:10.1308/003588410X12771863936684.
67. Clifford C, Ayre C, Edwards L, Guy S, Jones A. Acute knee clinics are effective in reducing delay to diagnosis following anterior cruciate ligament injury. Knee. 2021; 30:267-274. doi:10.1016/j.knee.2021.04.007.
68. Joseph AM, Collins CL, Henke NM, Yard EE, Fields SK, Comstock RD. A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. J Athl Train. 2013; 48(6):810-817. doi:10.4085/1062-6050-48.6.03.
69. Webster KE, Feller JA. A research update on the state of play for return to sport after anterior cruciate ligament reconstruction. J Orthop Traumatol. 2019; 20(1):1-7. doi:10.1186/s10195-018-0516-9.
70. Mostafaee N, Negahban H, Shaterzadeh Yazdi MJ, Goharpey S, Mehravar M, Pirayeh N. Responsiveness of a Persian version of Knee Injury and Osteoarthritis Outcome Score and Tegner activity scale in athletes with anterior cruciate ligament reconstruction following physiotherapy treatment. Physiother Theory Pract. 2020; 36(9):1019-1026. doi:10.1080/09593985.2018.1548672.
71. Randsborg P-H, Adamec D, Cepeda NA, Ling DI. Two-year Recall bias after ACL reconstruction is affected by clinical result. JB JS Open Access. 2021; 6(1) doi:10.2106/JBJS.OA.20.00164.
72. Zadro JR, Pappas E. Time for a different approach to anterior cruciate ligament injuries: educate and create realistic

expectations. Sports Med. 2019; 49:357-363. doi:10.1007/s40279-018-0995-0.
73. Ardern CL, Österberg A, Sonesson S, Gauffin H, Webster KE, Kvist J. Satisfaction with knee function after primary anterior cruciate ligament reconstruction is associated with self-efficacy, quality of life, and returning to the preinjury physical activity. Arthroscopy. 2016; 32(8):1631-1638. e3. doi:10.1016/j.arthro.2016.01.035.
74. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Relationships between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. Am J Sports Med. 2004;32(3):629-634. doi:10.1177/0363546503261722.
75. Bergerson E, Persson K, Svantesson E, et al. Superior outcome of early ACL reconstruction versus initial non-reconstructive treatment with late crossover to surgery: a study from the Swedish National Knee Ligament Registry. Am J Sports Med. 2022; 50(4):896-903. doi:10.1177/03635465211069995.
76. Davies L, Cook J, Leal J, et al. Comparison of the clinical and cost effectiveness of two management strategies (rehabilitation versus surgical reconstruction) for non-acute anterior cruciate ligament (ACL) injury: study protocol for the ACL SNNAP randomised controlled trial. Trials. 2020; 21:1-16. doi:10.1186/s13063-020-04298-y.
77. Tashman S, Zandiyeh P, Irrgang JJ, et al. Anatomic single-and double-bundle ACL reconstruction both restore dynamic knee function: a randomized clinical trial—part II: knee kinematics. Knee Surg Sports Traumatol Arthrosc. 2021; 29:2676-2683. doi:10.1007/s00167-021-06479-x.
78. Kato Y, Ingham SJ, Kramer S, Smolinski P, Saito A, Fu FH. Effect of tunnel position for anatomic single-bundle ACL reconstruction on knee biomechanics in a porcine model. Knee Surg Sports Traumatol Arthrosc. 2010; 18:2-10. doi:10.1007/s00167-009-0916-8.
79. Mascarenhas R, Cvetanovich GL, Sayegh ET, et al. Does double-bundle anterior cruciate ligament reconstruction improve postoperative knee stability compared with single-bundle techniques? A systematic review of overlapping meta-analyses. Arthroscopy.2015; 31(6):1185-1196. doi:10.1016/j.arthro.2014.11.014.
80. Boyer J, Meislin RJ. Double-bundle versus single-bundle ACL reconstruction. Bull NYU Hosp Jt Dis. 2010; 68(2):119-26.
81. Pioger C, Saithna A, Rayes J, et al. Influence of preoperative tunnel widening on the outcomes of a single stage–only approach to every revision anterior cruciate ligament reconstruction: an analysis of 409 consecutive patients from the SANTI study group. Am J Sports Med. 2021; 49(6):1431-1440. doi:10.1177/0363546521996389.
82. Johnson DH, Maffulli N, King JB, Shelbourne KD. Anterior cruciate ligament reconstruction: a cynical view from the British Isles on the indications for surgery. Arthroscopy. 2003; 19(2):203-209. doi:10.1053/jars.2003.50031.
83. Frobell RB, Roos EM, Roos HP, Ranstam J, Lohmander LS. A randomized trial of treatment for acute anterior cruciate ligament tears. N Engl J Med. 2010; 363(4):331-342. doi:10.1056/NEJMoa0907797.
84. Reijman M, Eggerding V, van Es E, et al. Early surgical reconstruction versus rehabilitation with elective delayed reconstruction for patients with anterior cruciate ligament rupture: COMPARE randomised controlled trial. BMJ. 2021:372:n375.doi:10.1136/bmj.n375.
85. 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 Med. 2022; 52(5):1091-1102. doi:10.1007/s40279-021-01600-z.