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Optimizing the Return to Sport (RTS) Process Following Anterior Cruciate Ligament Reconstruction (ACLR)

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HIGHLIGHT: Time-based criteria (6–9 months) → OBSOLETE
NEW STANDARD: Biology + Biomechanics + Psychology + Sport-specificity

Abstract
Introduction: Return to sports (RTS) following anterior cruciate ligament reconstruction (ACLR) is a critical and multifaceted stage of rehabilitation. The traditional approach, based on rigid time frames (6–9 months), is increasingly giving way to modern, individualized, criteria-based protocols. The aim of this study is to synthesize the current literature (2021–2026) on optimizing the decision-making process for RTS after ACLR.
Materials and Methods: A review of the scientific literature from the PubMed, Scopus, and Web of Science databases for the years 2021–2026 was conducted. Studies evaluating the effectiveness of biological criteria, symmetry indices, functional tests, and patients' psychological readiness were analyzed.
Results: The analysis showed that the process of graft ligamentization often takes more than 2 years, which calls into question the safety of early RTS based solely on the time criterion. The commonly used limb symmetry index (LSI ≥ 90%) has low predictive value and may mask bilateral muscle strength deficits caused by arthrogenic inhibition (AMI). Standard horizontal jump tests have proven insufficient; it is essential to incorporate vertical and lateral jump tests, as well as three-dimensional biomechanical analysis of movement. Psychological readiness (measured by the ACL-RSI scale) and the level of kinesiophobia are key determinants of success, showing a strong correlation with the risk of re-injury. In rotational sports, on-field rehabilitation based on reactive agility is crucial.
Conclusions: A safe return to sport (RTS) after ACLR requires moving away from time-based criteria in favor of multidimensional algorithms based on objective biomechanical, functional, and psychological tests. The decision to return to competition should be a continuous process carried out by an interdisciplinary team of specialists to minimize the risk of secondary injury.

Keywords: ACLR, return to sport, LSI, ligamentization, psychological readiness, biomechanics.

Content

1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most serious and common injuries in competitive sports, particularly in sports that require sudden changes in running direction. The primary goal of anterior cruciate ligament reconstruction (ACLR) is to restore full stability to the knee joint and enable the athlete to safely return to sport (RTS—Return to Sport). Despite tremendous advances in surgical techniques and physical therapy protocols, global success rates remain alarming: only 55–65% of athletes return to competition at their pre-injury level, and the rate of re-injury to the reconstructed joint reaches as high as 20–30%, particularly among the youth population.

Modern sports medicine indicates that the main cause of such a high failure rate is the incorrect clearance of patients for full competitive loads. Historically, return-to-sport (RTS) clearance was based on rigid time frames (e.g., return after 6 or 9 months) and an isolated assessment of muscle strength and jump symmetry (LSI index). Today, however, it is known that this approach is highly inadequate. These tests do not reflect the slow, biological process of graft maturation (ligamentization); they can mask deep, asymmetric biomechanical deficits in movement quality; and they completely overlook psychosocial factors, such as kinesiophobia or fear of re-injury. The lack of integrated, objective discharge criteria results in the premature exposure of histologically immature tissues to extreme shear and rotational forces on the field.

The aim of this literature review is to provide a comprehensive synthesis of current knowledge (from 2021–2026) on multidimensional decision-making algorithms in the process of returning to sports after ACL reconstruction. This study critically analyzes the pathophysiology of graft maturation, the diagnostic value of classic functional tests, the key role of psychological readiness, and the specifics of load management in rotational sports.

2. The Biology of Graft Maturation (Ligamentization) and the Risk of Secondary Injuries

Decisions regarding return to sport (RTS) after anterior cruciate ligament reconstruction (ACLR) are still based more on functional tests and time-based criteria than on a direct assessment of graft biology. This is because complete tissue remodeling and histological maturity of the tendinous structures extend far beyond the standard timeframe for returning to initial loading [1]. The discrepancy between the biological integration of the graft and the clinical recovery of motor function is one of the main pathomechanisms underlying secondary injuries to the reconstructed joint.

The process of healing and remodeling of an autogenous tendon graft into a structure resembling a native ligament—known as ligamentization—is not a uniform phenomenon, but rather a sequence of three closely interrelated phases at the cellular and molecular levels [2]. First, the inflammatory phase occurs, which is initiated immediately after tissue implantation. It is characterized by massive infiltration of immune cells and a signaling cascade of pro-inflammatory cytokines, particularly interleukin-1 beta (IL-1β), tumor necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6) [2]. This is immediately followed by the proliferative phase, dominated by the activity of fibroblasts and mesenchymal stem cells, which intensively synthesize type III collagen, accompanied by enhanced neovascularization stimulated by vascular endothelial growth factor (VEGF) [2]. The entire process culminates in the longest phase of remodeling, during which gradual tissue metabolism occurs. During this period, type III collagen is successively replaced by the mechanically stronger type I collagen, and the phenomenon of mechanotransduction—that is, the cellular response to physical loads—aids in the proper, axial alignment of the newly formed collagen fibers [2].

Histological studies and advanced imaging analyses demonstrate that the biological maturation of the graft proceeds much more slowly than the recovery of functional parameters, and the ligamentization process may take 2 years or longer [1]. Sequential magnetic resonance imaging, utilizing quantitative T2 mapping and signal-to-noise ratio (SNQ) assessment, shows that the first year after surgery is characterized by tremendous tissue dynamics [1]. T2 and SNQ values rise sharply between the 3rd and 6th months, reflecting hypervascularization and cellular proliferation, and then gradually decline between the 6th and 12th months, confirming ongoing, as-yet-unfinished structural remodeling [1].

In skeletally immature patients—that is, children and adolescents—this progression is further delayed. Magnetic resonance imaging (MRI) indicators of graft maturity show minimal changes between 6 and 12 months after transphyseal ACL reconstruction (ACLR), with significant structural improvement not evident until between 12 and 24 months [3]. This highlights a significant clinical gap—standard RTS tests, such as muscle strength assessments or jump tests, achieve satisfactory LSI parameters during a period when the biological structure of the graft is histologically immature and susceptible to injury [1].

Returning to full sports activities too early is a key, independent risk factor for re-injury, a finding that is particularly evident among young athletes. In the pediatric population, rates of graft re-rupture following ACLR range from 0% to as high as 35%, and the overall rate of subsequent ACL injuries—including both the graft and the ligament in the contralateral limb—affects an average of 22% of patients, showing a direct association with young age and early RTS [4].

Cohort studies in adolescents confirm the protective effect of delaying a return to play: each additional month of postponing the decision to return to sports reduces the risk of a secondary ACL injury by 13%, while each additional year of chronological age reduces this risk by 27% [5]. In adolescent athletes, structural damage accumulates in the early phase following return to play—the median time to graft failure is approximately 14 months after surgery [5].

However, simply postponing the decision until the 12th month does not completely eliminate the risk in the high-risk group. Long-term analyses show that among young patients advised to delay their return to sports until one year after surgery, the rate of subsequent knee injuries remained at 33% for those who followed the recommendations and 32% for those who actually returned after 12 months [6]. This demonstrates that the passage of time is a necessary condition for biological tissue integration, but not the only one—a safe return requires integrated medical, physical therapy, and biomechanical clearance.

3. Assessment of quadriceps strength, limb symmetry index (LSI), and neuromuscular control in the RTS procedure

An analysis of the scientific literature on return to sport (RTS) following anterior cruciate ligament reconstruction (ACLR) focuses on three interrelated issues: restoration of quadriceps strength, the diagnostic value of the limb symmetry index (LSI), and the integration of neuromuscular training into the rehabilitation process. Although regaining optimal knee extensor strength remains a key element of rehabilitation, current scientific evidence clearly indicates that an isolated assessment of the LSI parameter is not a reliable tool for verifying readiness to return to sport, nor does it reflect the patient's normalized motor patterns [7, 8].

Persistent quadriceps strength deficits at the time of clearance for sports activities and thereafter are a common phenomenon in patients following ACLR surgery. Systematic reviews indicate that in most of the analyzed studies, the mean LSI score for the quadriceps is below 90% at the time of return to sports, which occurs on average around the eighth month after surgery [8]. Compared to a matched control group of healthy individuals, the operated limb exhibits significant structural weakness for up to four years after surgery, although the severity of this deficit tends to decrease over time [9]. Insufficient restoration of muscle strength directly correlates with rates of secondary injuries. Reduced symmetry of the knee extensors correlates with a higher rate of re-injury, reaching 33% in patients with an LSI score < 90% compared to just 13% in those who reached or exceeded the 90% threshold [7]. Importantly, higher relative quadriceps strength in the operated limb increases the overall risk of ACL re-injury with a relative risk (RR) of 1.69; however, this association loses statistical significance once athletes regain full symmetry at a level of at least 90% [10]. The most rapid rate of strength adaptation occurs between the sixth and ninth months of recovery, which in a population of adolescent athletes results in an increase in the average LSI from 85.0% to 92.5% [11].

Although the LSI is widely used in clinical practice with a strict cutoff of >= 90%, it has very limited predictive value in the context of a safe return to play. Critical methodological analyses demonstrate the low discriminatory power of this parameter in distinguishing patients at risk of secondary injury, where the area under the operating characteristic curve is merely AUC = 0.50–0.59, and unit increases in the index or its deviations from perfect symmetry have no effect on protection against re-injury [7]. The primary drawback of the LSI is its tendency to overestimate the actual function of the operated limb, which stems from the fact that the non-operated limb also weakens during long-term rehabilitation, and high symmetry itself may mask a profound, bilateral deficit in absolute muscle strength [9, 12]. Achieving LSI thresholds six months post-surgery does not allow for predicting initial success over a two-year period, whereas specific performance tests for individual limbs and the ACL-RSI psychological readiness questionnaire prove to be predictors with significantly greater sensitivity [13]. In the pediatric population, relying on LSI criteria poses a particular risk, as biomechanical parameters of movement may remain severely impaired despite formal compliance with symmetry standards [14]. Young athletes who have successfully passed classic RTS tests achieve symmetry during landing not by normalizing the biomechanics of the operated limb, but by compensatorily unloading both lower limbs, which perpetuates pathological movement patterns [15].

Deficits in neuromuscular control, manifesting particularly during dynamic tasks such as landing or the takeoff phase of a jump, persist long after formal equalization of muscle strength and distance in single-leg jump tests. Cross-sectional studies demonstrate a lack of correlation between knee strength symmetry and landing biomechanics symmetry, and athletes with high LSI scores still generate lower knee extension torques and lower vertical ground reaction forces compared to a healthy control group [16]. Furthermore, excellent symmetry in the triple hop for distance test can effectively mask glaring deficits in knee joint work production, which patients compensate for through excessive engagement of the hip joint, pelvis, and trunk [17]. The key pathophysiological basis for these chronic disorders is arthrogenic muscle inhibition (AMI) and the phenomenon of central cortical inhibition, which together block the full recruitment of motor units in the quadriceps muscle [18]. An effective method for overcoming this mechanism is the implementation of neuromuscular electrical stimulation (NMES) as a supplement to standard physical therapy, with the timing of protocol initiation being of critical importance. The use of NMES within the first week after surgery yields significantly better results in strength recovery than its implementation at a later date, showing standardized mean differences (SMD) of 1.48 and 0.44, respectively [19]. For this reason, current guidelines unequivocally recommend moving away from isolated strength tests in favor of multidimensional RTS decision-making algorithms, which take into account advanced biomechanical assessment, proprioception, neurocognition, and the patient's psychological readiness [12, 18, 20].

4. Psychosocial Factors Influencing Readiness to Return to Sport and Kinesiophobia

A successful return to sports (RTS) following anterior cruciate ligament reconstruction (ACLR) is determined not only by mechanical and structural factors but equally by the patient's psychological profile. The main barriers limiting the recovery of pre-injury athletic performance are fear of re-injury and kinesiophobia. Contemporary medical literature from 2021–2026 points to a strong correlation between subjective psychological readiness and objective functional outcomes, which redefines the criteria for therapeutic success in sports medicine [21, 22].

Neuro-orthopedic analyses demonstrate that subjective psychological readiness for competitive loads is not a direct function of muscle strength recovery or jump symmetry (LSI). A meta-analysis involving 3,744 patients showed that athletes who successfully returned to competition scored significantly higher on the ACL Return to Sport after Injury (ACL-RSI) scale and lower on the Tampa Scale of Kinesiophobia (TSK) compared to those who did not resume activity [21]. Crucially, these differences persist even when objective knee function assessment scores are nearly identical [21]. In contrast, differences in purely clinical questionnaires, such as the IKDC (International Knee Documentation Committee), did not reach the minimum clinically important difference (MCID) between the two groups [21].

At the 12-month postoperative mark, biomechanical factors predict somatic sports function much more accurately than the ACL-RSI index alone, where only reduced jump distance shows a weak, negative correlation with mental readiness [23]. This suggests that the central nervous system's perception of joint stability is governed by regulatory mechanisms different from those involved in isolated force generation. Network analysis studies have shown that the key components of the ACL-RSI structure are fear of re-injury and a sense of psychological freedom during sports participation, whereas general confidence in the knee only gains significance after an actual return to game-level loads [24].

Fear of re-injury to joint structures is defined as the primary cause of withdrawal from competitive sports and permanent limitation of physical activity following musculoskeletal injuries [25]. In patients awaiting ACLR surgery, the severity of kinesiophobia as measured by the TSK scale is the only independent factor negatively associated with the ACL-RSI index [26]. Systematic reviews estimate that individuals with elevated kinesiophobia are 17% less likely to successfully return to their original sport [26, 27].

From a clinical perspective, a decrease in the ACL-RSI score and an increase in the TSK-11 score correlate with persistent, subjective knee symptoms between 6 and 12 months post-surgery, with odds ratios (OR) of 8.6 and 3.9, respectively, for each standard deviation [28]. This phenomenon is also directly reflected in the athlete's motor performance. Advanced machine learning algorithms, based on three-dimensional biomechanical analysis, classify patients with high and low levels of fear with 75.6% accuracy [29]. This demonstrates that kinesiophobia induces measurable, pathological movement patterns (e.g., kinematic stiffness of the limb, avoidance of full flexion) that impair landing and running dynamics [29].

The influence of psychological factors on the risk of recurrent ligament rupture exhibits complex dynamics. High scores on the TSK-11 scale (particularly scores above 19 points) have been associated in some cohorts with a risk of secondary graft injury or contralateral rupture that is as much as 13 times higher, which results from asymmetric overloading of the musculoskeletal system under the influence of anxiety [30]. On the other hand, in high-risk groups (e.g., young female athletes), athletes who had suffered a secondary ACL injury paradoxically exhibited higher ACL-RSI scores and returned to sports more quickly [31]. This suggests that extremely high psychological readiness may sometimes reflect a cognitive underestimation of competition risk, leading to aggressive behavior on the field before tissues have fully healed biologically [31].

Modern sports medicine, however, demonstrates that a patient's psychological profile is a modifiable parameter. The implementation of cognitive-behavioral physical therapy (CBPT) in randomized controlled trials resulted in a significant improvement in the ACL-RSI score, self-efficacy, resilience, and objective knee function [32]. Interestingly, this intervention did not alter the results of the TSK scale itself [32]. The latest psychometric reports suggest that the TSK questionnaire may correlate poorly with the ACL reconstruction population—especially during the asymptomatic phase, where pain is not the dominant factor—and does not show direct convergence with the construct of the ACL-RSI scale [33].

Clinical conclusions dictate that the prediction of a safe return to sports (RTS) should be based on the integration of psychometric tools (e.g., the ACL-RSI with a cutoff score above 47 points at 9 months, characterized by 85% sensitivity [34]) with a rigorous battery of functional tests under the close supervision of a licensed medical team.

5. Criteria Based on Functional Tests (Battery Testing) in Assessing Readiness to Return to Sport

The shift from traditional rehabilitation protocols based on rigid time frames to advanced algorithms based on objective criteria (criterion-based progression) represents a key paradigm in modern sports medicine. The process of return to sport (RTS) following anterior cruciate ligament reconstruction (ACLR) is currently defined as a continuous spectrum (continuum), in which progress depends on objective physical data, functional assessment, and psychological readiness, rather than on the time elapsed since surgery [35]. Decisions based solely on a calendar-based criterion are insufficient and should be completely abandoned [35]. Clinical studies demonstrate that the implementation of structured criteria significantly improves limb symmetry indices (LSI), scores on subjective questionnaires (KOOS), and reduces pain and joint effusion [36, 37]. Nevertheless, the literature still lacks a single, universally validated set of tests, and diagnostic procedures are highly heterogeneous, rarely combining simultaneous assessment of strength, jumping ability, and quality of movement [34, 35].

Single-leg hop tests are the most common component of functional assessment, serving as an indicator of muscle strength and neuromuscular control [38]. However, the classic battery based on four horizontal hops has limitations in detecting subtle motor deficits [39]. Recent reports indicate that modifying the battery by incorporating vertical hops and side hops demonstrates significantly higher diagnostic sensitivity and discriminative power [39].

It has been shown that the side hop allows for the detection of asymmetries that remain undetected during simpler linear tasks [39]. In turn, among collegiate athletes, the single-leg vertical jump test revealed significantly greater interlimb deficits (mean LSI of 84.5%) compared to horizontal tests, where LSI scores were falsely elevated, ranging from 94% to 98% [40]. Passing this jump battery is associated with an absolute 11% reduction in the risk of secondary ACL injury among athletes participating in rotational sports [39].

Despite their high clinical utility as tools for monitoring progress, isolated functional tests cannot be treated as a binary, black-and-white indicator of “safety” against re-injury [12]. Systematic reviews confirm that common jump and strength tests, when used in isolation, have limited predictive value for assessing the risk of re-injury or a patient’s long-term health outcomes [41, 42].

The main structural problem is that symmetry in jump distance (LSI >90%) can effectively mask profound biomechanical deficits [17]. Athletes meeting this criterion exhibit marked asymmetry in knee joint work production in three-dimensional motion analysis, compensating for the lack of power through excessive contribution from the hip, pelvis, and trunk [17]. Furthermore, pure motor performance is not synonymous with the quality of the movement pattern; analyses show no correlation between LSI values and dedicated scales for assessing movement quality (e.g., Quality First), which necessitates conducting independent, two-pronged evaluations [43].

Given the limitations of biomechanical laboratory tests, the assessment of psychological readiness becomes an integral part of predicting a successful RTS [35, 44]. The ACL Return to Sport after Injury (ACL-RSI) questionnaire demonstrates high predictive value in terms of returning to pre-injury athletic performance levels in situations where physical tests alone lack discriminative power [34].

In network meta-analyses, it is psychological readiness that achieves the highest effect size with regard to the success of a sustainable return to competition [44]. The final decision-making algorithm should therefore involve the serial and multifaceted integration of muscle strength measurements, highly sensitive jump tests (vertical and lateral), qualitative assessment of kinematics, and psychological readiness, and individual clearance to compete must always be supervised by a licensed sports clinician [34, 35].

6. Specifics of Returning to Sports in Rotational Disciplines

Authorizing a return to full competitive activity in sports that require sudden changes in direction, turns, and rotations (so-called cutting and pivoting sports, such as soccer, basketball, or handball) is one of the most difficult challenges in the postoperative process. Due to the extreme shear and torsional forces acting on the graft, it is crucial to move away from rigid time frames in favor of structured, sport-specific criteria. The current management model focuses on three complementary areas: late-stage on-field rehabilitation, individualized load management, and multifaceted criteria for discharge from close medical supervision [35, 45, 46].

The final phase of rehabilitation for athletes in rotational sports is based on specific on-field training sessions, which serve as a direct bridge between clinical rehabilitation and a return to full match loads [46]. The key principle of this stage is the progression from fully controlled and planned movements to reactive agility, performed under neurocognitive pressure and in the presence of an opponent [46]. This type of stimulation aims to re-establish motor control and minimize the risk of secondary injury [46].

The rehabilitation program must be closely tailored to the motor profile of the specific sport (e.g., soccer or basketball), where repetitive decelerations, accelerations, and dynamic changes in direction pose the highest risk of recurrent ligament injury [47, 48]. Despite widespread consensus on the validity of these measures, the standardization of procedures within specific sports, such as soccer, remains highly heterogeneous, and integrated assessment batteries that simultaneously evaluate strength, jumping ability, and movement quality are still in the minority [38]. From the athletes' perspective, a safe return to play requires a sequential, gradual increase in the intensity of movement tasks, avoiding time pressure, and continuing preventive neuromuscular training even after resuming their careers [48, 49].

Workload management during the RTS phase following ACL reconstruction is based on a strategy of graduated chronic loading, replacing the dogmatic search for a single, universal threshold value [50, 51]. The gradual accumulation of volume and intensity during on-field training not only allows for the restoration of sport-specific motor skills but also stimulates the athlete's psychological adaptation [46]. Current guidelines recommend basing progression on the achievement of successive milestones (milestone-based progression) rather than on rigid calendar schedules, which applies to both postoperative protocols and conservative treatment [51, 52].

A major methodological limitation of the current state of knowledge is the lack of unambiguous, high-quality data defining the optimal dose-response relationship with regard to the volume and intensity of exercise following ACLR [50]. This research gap explains why the concept of load management, although widely recognized as a key element of prevention, is characterized by a low degree of operational standardization in everyday clinical practice [50, 53].

Approval for a return to full competition should not be a single point in time, but rather a continuous process, progressing from return to participation, through return to sport, to regaining baseline performance [35]. It has been shown that fully completing the rehabilitation protocol and meeting objective discharge criteria drastically increases the chances of a successful return to sport (RTS)—in a population of male athletes, those meeting these requirements were nearly six times more likely to regain their pre-injury athletic level [54]. Importantly, among athletes who passed rigorous tests, returning to competition before the end of the ninth month was not associated with an increased rate of ACL re-injury compared to those returning later, confirming the primacy of functional readiness over the timeline alone [54].

The standard battery of tests authorizing the resumption of sports activities typically includes achieving full and pain-free range of motion in the joint, the complete absence of effusion and pain, as well as demonstrating symmetrical neuromuscular control in single-leg tasks [45, 55]. A key element of this assessment is also confirming symmetry in the strength of the quadriceps, the hamstring group, and the hip rotators at a level of at least 90% of the limb symmetry index [45, 55]. Despite the implementation of these criteria, global statistics on return to competitive sports after ACLR continue to hover around moderate rates of 55%–65%, and the risk of secondary injury among young athletes participating in rotational sports remains high [46, 50, 55]. The reasons for giving up sports often go beyond purely physical deficits, as psychological factors—such as fear of re-injury, decreased self-confidence, a shift in life priorities, or loss of interest in the sport—play a key role [56, 57]. Therefore, any decision to return to competition-level training in sports with high turnover rates requires a multi-level, individualized assessment by a licensed sports clinician.

7. Conclusions

A review of the current literature from 2021–2026 clearly indicates that a safe return to sports (RTS) following anterior cruciate ligament reconstruction (ACLR) requires a complete shift away from traditional, rigid time frames in favor of individualized, multidimensional algorithms based on objective criteria.

The following key conclusions for clinical and sports practice emerge from the analysis:

1. **The primacy of biology over time:** The process of ligamentization and histological maturation of the graft takes significantly longer (often more than 2 years) than functional recovery. Relying solely on the passage of time (e.g., 6 or 9 months) leads to premature exposure of immature structures to overload, which drastically increases the rate of secondary injuries, especially in adolescents.
2. **Critical evaluation of the LSI:** The commonly used limb symmetry index (LSI ≥ 90%) has low predictive value. It may falsely mask profound, bilateral muscle weakness and pathological movement compensations caused, among other things, by arthrogenic muscle inhibition (AMI).
3. **The Evolution of Functional Tests:** Standard horizontal jump tests are insufficient. Modern return-to-sport (RTS) test batteries must include tasks with higher diagnostic sensitivity (vertical and lateral jumps) and combine quantitative performance assessment with qualitative analysis of three-dimensional biomechanics of movement (e.g., landing technique).
4. **The Necessity of Psychological Evaluation:** Mental readiness, fear of re-injury, and kinesiophobia are just as significant barriers to return to sport (RTS) as physical deficits. Subjective assessment of mental state using the ACL-RSI scale strongly correlates with ultimate success in returning to sport and should be an integral part of every discharge procedure.
5. **The Specifics of Rotational Sports:** In sports requiring sudden changes of direction (cutting sports), a prerequisite for regaining pre-injury athletic performance is the implementation of on-field rehabilitation incorporating elements of reactive agility and gradual chronic workload management.

In summary, the decision to return to competitive sports is not a single point in time but a complex continuum. Minimizing the risk of graft re-rupture requires close collaboration among a multidisciplinary medical team that integrates the patient’s biological, biomechanical, and psychosocial parameters.

Disclosure

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