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REVIEW ARTICLE

# Should Return to Sport be Delayed Until 2 Years After Anterior Cruciate Ligament Reconstruction? Biological and Functional Considerations

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**Abstract** Anterior cruciate ligament (ACL) tears are common knee injuries sustained by athletes during sports participation. A devastating complication of returning to sport following ACL reconstruction (ACLR) is a second ACL injury. Strong evidence now indicates that younger, more active athletes are at particularly high risk for a second ACL injury, and this risk is greatest within the first 2 years following ACLR. Nearly one-third of the younger cohort that resumes sports participation will sustain a second ACL injury within the first 2 years after ACLR. The evidence indicates that the risk of second injury may abate over this time period. The incidence rate of second injuries in the first year after ACLR is significantly greater than the rate in the second year. The lower relative risk in the second year may be related to athletes achieving baseline joint health and function well after the current expected timeline (6–12 months) to be released to unrestricted activity. This highlights a considerable debate in the return to sport decision process as to whether an athlete should wait until 2 years after ACLR to return to unrestricted sports activity. In this review, we present evidence in the literature that athletes achieve baseline joint health and function approximately 2 years after ACLR. We postulate that delay in returning to sports for nearly 2 years will significantly reduce the incidence of second ACL injuries.

**Key Points**

Young, active anterior cruciate ligament (ACL) reconstructed (ACLR) athletes who return to high-level sports sustain a disproportionately greater incidence of second ACL injuries within the first 2 years after ACLR.

The evidence in the literature indicates that the ACLR athletes do not regain baseline, or not significantly different from baseline, knee joint biological health and function until approximately 2 years after ACLR.

The incidence of second ACL injuries will significantly decrease if ACLR athletes delay a return to high-level activity until 2 years after ACLR.

## 1 Introduction

Anterior cruciate ligament (ACL) tears are common musculoskeletal injuries sustained by athletes who participate in landing and pivoting sports. ACL reconstruction

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(ACLR) is the current clinical standard to provide mechanical stability to the joint and return to sports (RTS) in a timely manner [1]. One of the most devastating, and all too common, complications following a return to activity is a second ACL injury. A systematic review of prospective studies with a minimum follow-up time of 5 years found that the pooled percentage of autograft failure rates and contralateral ACL tears was 5.8 and 11.8 %, respectively [2]. Long-term follow-up periods of ≥10 years have reported second injury rates between 23 and 27 % [3–5]. Several factors have been implicated in second ACL injury risk, including graft placement [6–8], graft type [9–13], sex [14–16], age [5, 14, 17–19], time from surgery [10, 20, 21], activity level [22, 23], and aberrant neuromuscular and biomechanical adaptations [24].

The active, young athlete who resumes activity following ACLR has a greater propensity for a second ACL injury [8, 9, 13, 14, 17–19, 25, 26]. The probability of a second injury increases three- to sixfold when the athlete is aged <20 years [19]. Injury rates in this younger cohort have been reported to be almost as high as 30 % in the literature [5, 17, 20, 24]. In addition, the increased risk in this group is apparent immediately upon returning to sports. The evidence strongly indicates that second ACL injury risk is greatest within the first 2 years after ACLR for young athletes returning back to high-level sports [15, 19, 20, 22, 24, 26]. A young athlete who returns to sport within 1 year is 15 times more likely to suffer a second ACL injury than a healthy athlete with no medical history of a knee injury [15]. This elevated risk remains evident within 2 years of returning to activity, when an athlete is approximately six times more likely to sustain a second injury than an uninjured counterpart [20]. While the risk in this young cohort is high initially, this evidence indicates that the risk may be abated over time as athletes are still recovering baseline joint health and function. These athletes are at a disproportionately higher risk of second ACL injury within the first 2 years after ACLR. Therefore, waiting to reintegrate into high-level sports activity will significantly benefit the ACLR athlete.

The high secondary injury rates within 2 years after ACLR in the young active cohort highlight the significant impact of returning to sport too early. The marked increase in early second ACL injuries also correspond with the shift from a more conservative postoperative treatment of ACLR athletes as described by Paulos et al. [27] to the accelerated rehabilitation program suggested by Shelbourne and Nitz [28]. The lower relative risk of second ACL injuries in athletes who delay a return to activity after ACLR may be related to graft healing, recovering knee joint homeostasis, and restoring normal joint motion prior to being released to unrestricted sports activity. A complete resolution of symptoms and deficits after ACLR may be directly related to the biological and functional recovery of the knee joint. In this review, we present the evidence that athletes achieve baseline joint health and function approximately 2 years after ACLR. The postulate outlined below is that a delay in return to unrestricted high-level sports participation for at least 2 years will significantly reduce the incidence of second ACL injuries.

## 2 Biological Recovery of the Knee

Athletes may require a longer postoperative recovery period than the typically advocated 6–12 months to facilitate the biological recovery of the joint [29]. The ACL graft must undergo repopulation and proliferation of cells, revascularization, and re-innervation to successfully restore the native properties of the ligament [30]. In addition, ACL graft maturation, through assimilation and re-ligamentization, is critical to the reinstatement of ACL integrity [31, 32]. These innate properties may be regained, but the current evidence indicates that this healing occurs at a slower rate than the timeframe in which athletes commonly return to activity [33–36]. Furthermore, trauma from the injury is not restricted to the ligament alone; it also affects the surrounding joint tissues. A majority of ACL tears occur as non-contact episodes that involve the knee absorbing a high external load causing substantial trauma to the articular cartilage and subchondral bone [37–40]. Partial recovery of the joint is deleterious and may lead to a knee joint environment that is unable to endure the forces associated with a return to activity. Therefore, if time from ACLR is utilized among the RTS criteria in determining whether an athlete is ready to RTS, it should ensure that the ACL graft and surrounding knee joint tissue are completely recovered prior to returning to sport. Ideally, an athlete returns to sport once ACL and whole joint integrity is re-established.

### 2.1 Bone Bruises

The prevalence of bone bruises concomitant with ACL injuries is high, as approximately 80 % of individuals present with subchondral lesions and bone marrow edema [38, 41, 42]. These occult osseous lesions are identifiable by magnetic resonance imaging (MRI) as alterations in signal intensity [43, 44]. Despite conflicting evidence of their clinical relevance and an absence of association with second ACL injury risk [45–48], the presence of bone bruises at follow-up may indicate that the knee has not normalized.

A recent systematic review [49] investigated the characteristics of bone bruises associated with ACL tears, their clinical relevance, and their progression over time. The studies that included follow-up imaging observed that chondral defects were still present 1 year after ACL injury [49]. One limitation of the studies that were included in the review was the relative short-term follow-up period of <2 years [49]. Hence, whether these effects persisted at 2 years post-injury is not clear. Boks et al. [50] performed a systematic review of follow-up studies to examine the natural course of post-traumatic occult bone lesions as detected by MRI imaging. A review of 13 studies demonstrated that a natural healing response may be observed for bone bruises after acute trauma, but the time to recovery may depend on the extent of disturbance [51]. At follow-up imaging, the percentage of complete resolutions of bone bruises in the knee ranged from 88 % after 11–16 months of follow-up to 100 % after 5–12 months of follow-up [51]. The course of healing was variable and possibly related to the severity and location of the bone bruise.

Costa-Paz et al. [47] conducted a follow-up study of bone bruises associated with ACL ruptures. Preoperative MRIs verified the presence of bone bruises and were used to develop a three-level classification system based on severity and location [47]. The more severe a bone bruise, the higher the classification it received. Follow-up MRIs were conducted at an average of 34 months following ACLR and revealed the resolution of all type I and type II bone bruises, except one type II [47]. However, all type III lesions had persistent evidence of abnormality on MRI scans that was consistent with cartilage thinning or cortical depression, indicating that recovery was not complete [47]. Bone bruises may be recovering up to 1 year following ACLR and require a longer recovery period than the standard timeline according to which athletes are returning to activity.

Bone scans are important tools to evaluate both osseous metabolic activity of the joint and potential bone loss resulting from the trauma of the injury [52]. Bone loss is not directly implicated in second ACL injury, but a metabolically active joint and substantial bone loss are signs of a degenerative joint environment and a knee that is not prepared for unrestricted sports activity. In addition, ACLR may slow the process of knee joint homeostasis, further delaying its full recovery [53]. Nyland et al. [54] conducted a systematic review of osseous deficits after ACL injury and ACLR. A review of the literature indicated that involved limb bone integrity is decreased after ACL injury and that premorbid bone integrity is not re-established after ACLR and accelerated rehabilitation [54]. Zerahn et al. [55] conducted a 2-year prospective cohort study that evaluated the relationship between subjective knee function (International Knee Documentation Committee [IKDC] score), self-reported signs of instability (Lysholm score), and bone mineral density (BMD). There was a significant decline in BMD in the proximal tibia of the ACLR limb at the 4- and 12-month follow-up compared with controls and the uninjured contralateral limb [55]. The BMD of the medial tibia had returned to normal levels at 24 months, but the lateral tibia had significantly lower BMD than the uninjured limb and healthy controls [55]. Furthermore, there was a significant improvement in Lysholm score, level of activity, and knee function at 24 months [55]. The improvement in self-reported knee function at 24 months was also associated with an increase in BMD in the ACLR limb [55]. In summary, the recovery of bone to baseline level may requisite a significant delay in a RTS of nearly 2 years [56–58].

### 2.2 Mechanoreceptors and Sensory Afferents

Sensory nerve fibers and mechanoreceptors (Golgi tendon organs, Pacinian corpuscles, and Ruffini nerve endings) account for nearly 3 % of the ACL's tissue volume and for the sensory function of the ligament [59, 60]. In addition, a reflex loop between these sensory constituents and the surrounding musculature is involved in dynamic joint stability and proprioception [61, 62]. However, once the ACL is disrupted, the native sensory function is lost and re-innervation is not fully restored, regardless of ACLR [63–65]. To compensate, ACLR athletes must develop extra-articular sensation and control of the joint through the mechanoreceptors and sensory nerve fibers in peri-articular tissue. This loss in sensory function is strongly indicated by proprioceptive deficits following ACL injury and ACLR [66, 67]. Because proprioception of the knee is not objectively defined and can be measured in several ways, we limit our discussion in this current opinion article to tasks of joint position matching and threshold to detection of passive moments, which are commonly measured for joint kinesthesia; however, we have discussed alternative, more sensitive and specific methodologies in a separate review [67].

This proprioceptive compensation strategy is not immediately developed, but is instead slowly gained long after ACLR and a release from sports participation. Iwasa et al. [68] evaluated 38 patients following a hamstrings tendon (HT) ACLR in joint position tasks from 3 to 24 months at 3-month intervals. A total of 30 patients had improved joint position sense up until the final follow-up at 24 months, whereas eight patients did not have any improvement in proprioception at any time in the course of the study [68]. This study indicated that a longer postoperative recovery may be required for a complete resolution of proprioceptive deficits. MacDonald et al. [69] conducted 'threshold to detection of passive movement' testing of ACL-deficient, ACLR with HT autograft, and ACLR with patellar tendon (PT) autograft at an average follow-up of

31 months. No statistically significant differences were observed during testing between the three groups at follow-up [69].

Deficits in proprioception are not exclusive to the ACL-injured and ACLR limb; they have been widely reported in the uninjured limb but to a lesser extent [70]. While symmetry is important, the assessment of proprioception using the contralateral limb is a fundamental issue that should be controlled. Roberts et al. [71] compared bilateral proprioceptive deficits in ACLR and healthy volunteers at a mean of 2 years from surgery and observed no differences at 2 years within or between groups during the active and visual reproduction tests [71]. Risberg et al. [72] investigated proprioception in ACLR and control cohorts with and without bracing. After controlled rehabilitation, the cohorts were studied at a mean follow-up of 2 years. No significant differences were observed during the threshold to detection of passive moments between the ACLR knees and the contralateral uninjured knees [72]. Further, there were no significant differences during the same task between the ACLR and control groups or the uninjured contralateral limbs and the control group [72]. These studies indicate that continued improvement in proprioceptive function is observed up to 2 years after ACLR.

The current evidence regarding proprioception presents conflicting results. Evidence indicating that proprioceptive function can be fully restored to baseline levels is limited. However, the longitudinal evidence indicates an improvement of proprioceptive function over time and a recovery to not significantly different from baseline well after athletes are commonly released to sports activity. Gokeler et al. [73] recently reviewed the literature to evaluate the clinical relevance of proprioceptive deficits. They found limited evidence to indicate that proprioceptive deficits detected by the current measurement techniques adversely affect function in ACL-deficient and ACLR athletes [73]. Further research is needed to develop more sensitive and relevant measurements for proprioception and sensorimotor function. However, the relative contribution of the loss of ACL sensory information to chronic joint dysfunction and second ACL injury risk is unclear.

### 2.3 Graft Maturation

The restoration of normal knee function may depend on ACL graft maturation toward a biologic structure similar to that of the native ACL. The healing and metaplasia of the ACL graft commonly became known as ligamentization [31]. Histological analysis of graft tissue from animal models is commonly used to study the early, remodeling, and mature phases of the ACL graft ligamentization sequence [32, 74]. The biomechanical properties of the ACL graft are significantly influenced by the remodeling phase, the phase in which the graft is mechanically the weakest and most susceptible to injury [30, 75]. Claes et al. [33] conducted a systematic review of the current literature on the ligamentization process in humans. A key finding from the review is that humans undergo the same ligamentization sequence as animals, but the timeline of healing is substantially different [33]. The ligamentization processes occurs in humans over a much longer duration than that originally observed in animal studies; specifically, humans have a much slower remodeling phase [33].

A recent systematic review examined the literature on the ligamentization process in HT autograft used in human ACLR [34]. Within this review, the results of the ligamentization process in HT autografts were compared with the other commonly used graft in ACLR, the PT autograft [34]. The results indicated that the HT autograft has a significantly delayed remodeling phase, which occurs between 12 and 24 months [34]. Alternatively, PT autografts undergo the remodeling phase during the 6- to 12-month timeline [34]. These time periods correspond not only to the time that athletes are returning to sport, but also to the time when athletes are at a greater risk for a second ACL injury.

A non-invasive approach to examine the ACL graft and its stages of healing in humans is achieved through various imaging modalities that are now clinically available [76]. A recovery to nearly native ACL properties in imaging studies is indicated approximately 2 years after ACLR. Vogl et al. [77] conducted a 2-year prospective study that evaluated the ACL graft healing process using contrast-enhanced MRI. Revascularization of the ACL graft closely resembled that of the native ACL at the 2-year follow-up [77]. Zaffagnini et al. [78] studied the histological ligamentization changes in PT autograft at 6, 12, 24, 48, and 120 months following ACLR using transmission electron microscopy (TEM). The results of the study indicated that progressive ultrastructural changes towards the normal ACL were observed for up to 24 months [78]. Notably, no further changes were observed in the TEM imaging after the 24-month time point after ACLR [78]. Variability in healing was observed in these studies, but longer follow-up periods indicated a complete structural and morphological resemblance to the native ACL [79–82]. A significant delay in RTS following ACLR to nearly 2 years may allow complete healing of the ACL graft and possibly the prevention of early failure in ACLR knees.

## 3 Functional Recovery of the Knee

Restoring mechanical stability after ACL injury by electing to undergo ACLR does not address residual functional deficits [83–85]. Postoperative rehabilitation protocols treat the localized dysfunction and related symptoms, including joint effusion, limited range of motion, and deficits in quadriceps muscle strength and activation. Functional impairments implicated in second ACL injury continue to persist when athletes are returning to sport and are measurable for several months afterwards [84–87]. The evidence in the literature indicates that the recovery of knee function is the last of the remaining sequelae to normalize following ACLR [88–91]. Specifically, ACLR athletes demonstrate characteristic deficits in neuromuscular control and knee extension strength that do not begin to reach baseline levels until at least 2 years after ACLR.

### 3.1 Neuromuscular Control

Similar to primary ACL injury, the majority of second ACL injuries occur as non-contact episodes [92], and failure to actively control the knee during multi-planar movements may lead to an increased risk of second ACL injury. A recent prospective study [24] screened 56 high-risk ACLR athletes at the time they were medically cleared to resume sports participation. At 1 year after the initial assessment and actively participating in sport, 13 of the athletes sustained a second ACL injury [24]. A combination of neuromuscular and biomechanical factors, including transverse plane hip moments, frontal plane knee angles, sagittal plane knee moments, and deficits in postural stability predicted second injury with 92 % sensitivity and 88 % specificity [24]. These findings are important because they demonstrate that residual deficits in neuromuscular control are highly predictive of a second ACL injury after athletes resume sports participation.

Persistent faulty neuromuscular characteristics are evident in even basic biomechanical tasks such as walking. Gokeler et al. [88] recently conducted a systematic review that included a comprehensive overview of kinematic and kinetic variables present during gait in athletes following ACLR. A review of over 20 studies with a mean gait analysis at 29.3 months (range between 3 weeks and 5.7 years) observed that altered biomechanics in all three planes are common after ACLR and may persist up to 5 years after ACLR [88]. A more recent systematic review and meta-analysis [89] compared the knee kinematic and kinetics during walking of ACLR knees to healthy controls and uninjured contralateral limbs. The analysis of 34 studies identified lower peak flexion moments during 6–12 months post-ACLR and lower peak flexion angles during 1–3 years and ≥3 years after ACLR [89]. However, the pooled data provided evidence of no significant difference between peak knee adduction moments after 3 years following ACLR [89]. The recovery of normal neuromuscular control during daily activities such as gait may be significantly delayed after ACLR.

To date, two studies have reported the progressive recovery of neuromuscular control during gait ≥2 years following ACLR. Roewer et al. [84] recruited a cohort of high-risk athletes and assessed knee strength and biomechanics during gait at 6 months and then again at 2 years after ACLR. The acute post-injury assessment revealed asymmetrical knee angles, knee moments, and hip and knee power that also persisted to 6 months after ACLR [84]. At 2 years after surgery, quadriceps strength continued to improve and the kinematic and kinetic asymmetries that were present at 6 months were resolved, which indicated that athletes have the capability to functionally improve up to 2 years after ACLR [84]. Webster et al. [93] also assessed longitudinal changes in knee biomechanics during gait at an initial assessment at 10 months and again at 3 years after ACLR. An improvement in knee extension and internal rotation was documented over time [93]. Primarily, knee biomechanics remained relatively unchanged from the initial and final assessment [93]. However, the results indicated that normal gait may recover over the longer time frames, past the 1-year time point [93].

Altered neuromuscular control is also commonly reported during sports-related, high-demand activities following ACLR. Sports-specific jumping tasks have revealed alterations in force generation and attenuation at the ACLR knee up to 2 years after ACLR and beyond [94–96]. Performance during functional hop testing is a common assessment for clearance of athletes for unrestricted sports activities. A recent systematic review [97] reported the results of functional performance testing at differing time points following ACLR. A review of 88 studies and nearly 5000 patients observed that the four standard hop tests (single-leg, cross-over, triple, and timed 6-m hop tests) were the common functional assessments [97]. The results indicated that athletes reach 90 % limb symmetry index (LSI) at 6–9 months postoperatively [97]. However, results from more demanding functional tasks, such as endurance hop testing, indicated larger deficits over the same 6- to 9-month time points [97]. These deficits appeared to normalize at 24 months post-ACLR, with reported LSI in the mid-90s, which are comparable to results from the standard hop tests [97].

More recently, groups have utilized more invasive techniques to study in vivo dynamic knee function after ACLR [98]. Dual fluoroscopy and dynamic stereo-radiography is becoming more widely accessible because it provides better precision and more reliability than the use of high-speed cameras or marker-based motion capture systems [98]. Hoshino et al. [99] investigated whether knee kinematics and joint contact mechanics can be restored after ACLR with a double-bundle or single-bundle graft using dynamic stereo X-ray to capture biplane radiographic images. The athletes were, on average, a little more than

1 year out from ACLR and were performing downhill treadmill running [99]. The study concluded that neither ACLR procedure restored normal knee kinematics or medial joint sliding [99]. In addition, developments in quantitative MRI have allowed researchers to evaluate the composition and structures within the knee. A recent study used volumetric dynamic imaging to assess contact patterns during an active knee flexion/extension task in athletes an average of 2 years post-ACLR [100]. There were no reported significant differences in cartilage thickness between the ACLR and healthy control groups [100]. However, the ACLR group demonstrated a greater reduction in the fraction of water bound by proteoglycan and greater contact in the medial and posterior portion of the knee than did the control group [100]. In contrast to the commonly used high-speed cameras, these systems are far more expensive, expose the patient to more radiation, and are highly complex. Regardless of technique used to assess kinematics and kinetics, athletes are still presenting with large deficits in the 6- to 12-month time frame, but are normalizing closer to 2 years after ACLR.

Failure to recover normal knee function may be related to the inability to restore intrinsic properties of the native ACL. Although functional asymmetries may abate over time, normal neuromuscular control may never fully recover following ACLR [88]. A new standard of neuromuscular control that involves deficits not significantly different from baseline function may be inevitable in some athletes.

### 3.2 Quadriceps Strength

Lower extremity muscle weakness is a debilitating and ubiquitous impairment resulting from ACL injury. Although the relative ratio between quadriceps and hamstring strengths has been implicated in primary ACL injury risk [101], the direct relationship of knee extensor and flexor strength to second ACL has not been assessed. The majority of sports medicine clinicians and physical therapists advocate a recovery of quadriceps and hamstring torque production equivalent to the contralateral limb prior to participating in high-level sports activity. However, the evidence in the literature strongly indicates that quadriceps strength deficits are commonly observed for several months and years following ACLR in spite of formal rehabilitation focusing on rebuilding muscle strength [91]. A systematic review and meta-analysis investigated the influence of graft choice on isokinetic muscle strength 4–24 months following ACLR [90]. The study observed athletes who elect to receive a PT autograft demonstrated a greater knee extensor deficit and lower knee flexor deficits than patients with an HT autograft [90]. Importantly, the strength deficits were unresolved up to 2 years following ACLR [90]. The impact of lower extremity muscle weakness has significant functional implications as athletes with greater strength deficits demonstrate decreased functional performance and landing strategies that increase risk of second ACL injury [102, 103].

Recovery of quadriceps and hamstring strength is commonly observed over time. However, evidence clearly indicates that athletes consistently demonstrate significant knee extensor and flexor strength deficits during the expected time frame to RTS, but these deficits begin to normalize approximately 2 years after ACLR. A few studies that demonstrate a recovery of knee strength at 2 years are highlighted below. Aune et al. [104] longitudinally compared isokinetic knee extensor and flexor strength between athletes who received two different autografts for ACLR. At 24 months after surgery, nearly symmetrical knee extensor and flexor strength measurements were reported within the groups, and significant differences between the two cohorts were not observed [104]. Further, Inagaki et al. [105] assessed clinical outcomes 2 years following ACLR and documented that average peak isokinetic knee extensor and flexor measurements at 2 years demonstrated symmetry comparable to that of an uninjured population (<15 % deficit) [105].

Longitudinal prospective randomized clinical trials may provide valuable insight into trends in clinical outcomes. In one such study, Aglietti et al. [106] assessed 120 athletes in a prospective randomized study to compare two unique autografts fixed with modern devices at 4, 12, and 24 months. An isokinetic dynamometer was used to measure concentric knee extensors and flexors muscle at 60°, 120°, and 180°/s [106]. At the 2-year follow-up evaluation, knee extensor and flexor strength of the involved limb was comparable to that of the contralateral side; in some instances, it was even greater [106]. Furthermore, a marked improvement in extensor strength was observed over time regardless of the graft type that only became symmetrical with the contralateral side 2 years postoperatively [106]. In addition, Maletis et al. [107] also conducted a similar prospective randomized study using similar autografts and assessment time points. Isokinetic knee extension/flexion measurements were also conducted at 60°, 180°, and 300°/s [107]. Similarly, at the 2-year follow-up, clinically meaningful significant differences were not observed in knee extension and flexion strength [107]. Extensor muscle strength once again significantly improved over time and became comparable to that of the contralateral side at 2 years [107]. It is common to measure variable measures of knee strength following ACLR, but the recovery of strength seems to be sustained beyond the 2-year time point.

Longitudinal studies of more than 2 years have also demonstrated the sustained recovery of knee strength.

Studies that evaluated athletes for over 5 years after ACLR reported quadriceps strength measurements comparable to those of a healthy athlete population, with minimal deficits of between 6 and 10 % [108–110]. Another benefit of delay of return to pre-injury level of activity for up to 2 years after ACLR is the recovery of baseline knee strength and a potential reduction of second ACL injury risk.

### 3.3 Effect of Surgical Techniques and Postoperative Rehabilitation

In addition, functional recovery of the knee after ACLR may be related to surgical techniques utilized in ACLR and postoperative rehabilitation programs. These topics are highly researched and discussed in sports medicine but consensus is minimal. Here, we give a brief overview of the recent evidence and how these factors may affect early failures. In particular, femoral tunnel placement during ACLR has highlighted the impact of surgical techniques on second ACL injury risk. A recent report has observed that femoral tunnel malposition was the most commonly cited reason for a graft failure in a large ACLR cohort [111]. Furthermore, the Danish Knee Ligament Registry observed an increased risk of revision after anteromedial femoral tunnel placement compared with a transtibial approach [112]. Current techniques in ACLR over the past several years have focused on reproducing more anatomical tunnel placement and graft geometry to restore knee kinematics [98]. Xu et al. [113] demonstrated in a cadaveric study that an anatomic anteromedial tunnel placement can lead to biomechanical advantages when compared with a non-anatomic placement, and the anatomic placement better restores knee kinematics to the native intact ACL state [113]. However, the anatomic placement had significantly greater in situ forces than the non-anatomic placement, making it more vulnerable to graft failure [113]. Therefore, delaying a return to activity longer than the expected timeline may significantly help the recovering knee withstand the forces of returning to sport. It is likely that misplaced tunnels are responsible for early traumatic failures and may predispose a graft to aberrant biomechanics, causing it to rupture at a later time [114]. Although differences in outcomes may be reported, it is generally thought that the recent trend in surgical practice of a more anatomic placement to resemble the native ligament is better for the outcome of the graft as long as it is allowed to heal completely [115, 116]. Because the significant majority of athletes undergo ACLR, it is also important to understand how surgery and rehabilitation together can be utilized to optimize patient knee outcomes.

Postoperative rehabilitation programs are considered essential for rebuilding lower extremity muscle strength and restoring joint mobility and neuromuscular control with the goal of returning to pre-injury levels of activity. Currently, there is little consensus regarding an optimal rehabilitation program to safety and effectively return athletes to their pre-injury level of sport. A systematic review of 33 randomized clinical trials observed that several of the studies had significant flaws and that little evidence could be derived from them [117]. The authors concluded there was evidence for high-intensity neuromuscular electrical stimulation, volitional exercises, and neuromuscular training [117]. More recently a randomized controlled trial assigned 74 ACLR patients to either a neuromuscular training program or a traditional strength training program and followed for 2 years after ACLR [118]. The neuromuscular training group reported greater global knee function and reduced pain during activity, while the strength training group demonstrated greater hamstring strength at 2 years post-ACLR [118]. However, there were no significant differences between the two groups in Cincinnati knee score at 1 and 2 years [118]. Grindem et al. [119] compared the preoperative and 2-year postoperative self-reported outcomes of ACLR patients who underwent progressive preoperative and postoperative rehabilitation compared with the institution's standard of care. The patients enrolled in the preoperative and postoperative rehabilitation program demonstrated significantly greater Knee Injury and Osteoarthritis Outcome Score (KOOS) in all subscales preoperatively and 2 years postoperatively than did patients in the standard of care group [119]. Furthermore, a group investigated whether there were any long-term differences (at 2–4 years after ACLR) in athletes who underwent a home-based or physical therapist-supervised rehabilitation program in the first 3 months after ACLR [120]. The home-based group had a significantly higher ACL quality of life questionnaire score at a mean of 38 months after ACLR, but there were no significant differences in knee extension/flexion range of motion, knee laxity, lower extremity strength, and IKDC score [120]. The optimal rehabilitation program is still unknown, and the lack of a standard rehabilitation treatment protocol is a major limitation to returning athletes back to sport safely. Regardless of the postoperative rehabilitation protocol, the outcomes following ACLR begin to normalize at nearly 2 years or later. The combination of time and comprehensive functional criteria is critical to return to high-demand activity, but the current approach of accelerated rehabilitation and timeline to recover is detrimental to the athlete.

Surgical techniques and postoperative rehabilitation programs are certainly a topic of ongoing debate and research studies. Importantly, regardless of surgical techniques and rehabilitation protocols, athletes returning to activity too early, prior to recovering baseline knee joint health and function, increase their risk for a subsequent

ACL injury. The evidence in the literature indicates that significantly delaying a return to high-level sports until nearly 2 years will benefit the athlete.

## 4 Conclusion

Deficits in knee function and biological health of the knee joint are all common up to 1 year following ACLR. A marked improvement in joint health and function and a resolution of symptoms is strongly indicated at 2 years and beyond following ACLR. The 2-year time point post-ACLR is not arbitrary but is evident based on a discerning review of the current evidence. Figure 1 shows a timeline of recovery strongly indicated by the current literature and presented in this current opinion article. The sports medicine community has made significant advances in surgical techniques, postoperative rehabilitation, and identification of risk factors for second injury, but this has not translated to a reduction in secondary ACL injury risk. The recovery of baseline knee health and function should be a fundamental requisite prior to returning to sport following ACLR.

In summary, the young and active athlete who returns to high-level landing, pivoting sports is at significantly greater risk for a second ACL injury [17, 19]. These injuries are also most frequent in the first 2 years after ACLR [22, 26]. Several risk factors are implicated in this increased risk of second ACL injury, including surgical factors (graft placement and type) [6, 7], demographics (sex and age) [121], activity level [17], sport [16], and neuromuscular and biomechanical factors [24]. Other anatomical and intrinsic risk factors have not been discussed in this article because these factors are not subject to change by delaying a RTS [122]. We have presented the evidence in the literature showing that at 2 years after ACLR, biological healing (absence of bone bruises, ACL graft maturation, and sensory restoration) has occurred and functional recovery (biomechanical and neuromuscular control and quadriceps strength) of the knee has normalized or is not significantly different from baseline. Therefore, delaying a return to high-level activity for high-risk athletes until 2 years after ACLR will restore knee joint homeostasis and significantly reduce the risk of subsequent injury.

One of the challenges to be faced with a new paradigm such as that advocated in the current article relates to the differential recovery of athletes following ACLR. Some young active athletes recover more quickly and successfully transition back to sports, as the majority of athletes safely return to some form of activity following ACLR. In addition, waiting 2 years after ACLR to return to pre-injury level of activity means that the athlete themselves, their coaches, and their parents must be willing to potentially not return at the same level of sport and to miss up to two seasons of their respective sport. This may have serious consequences for the athlete's immediate career and,

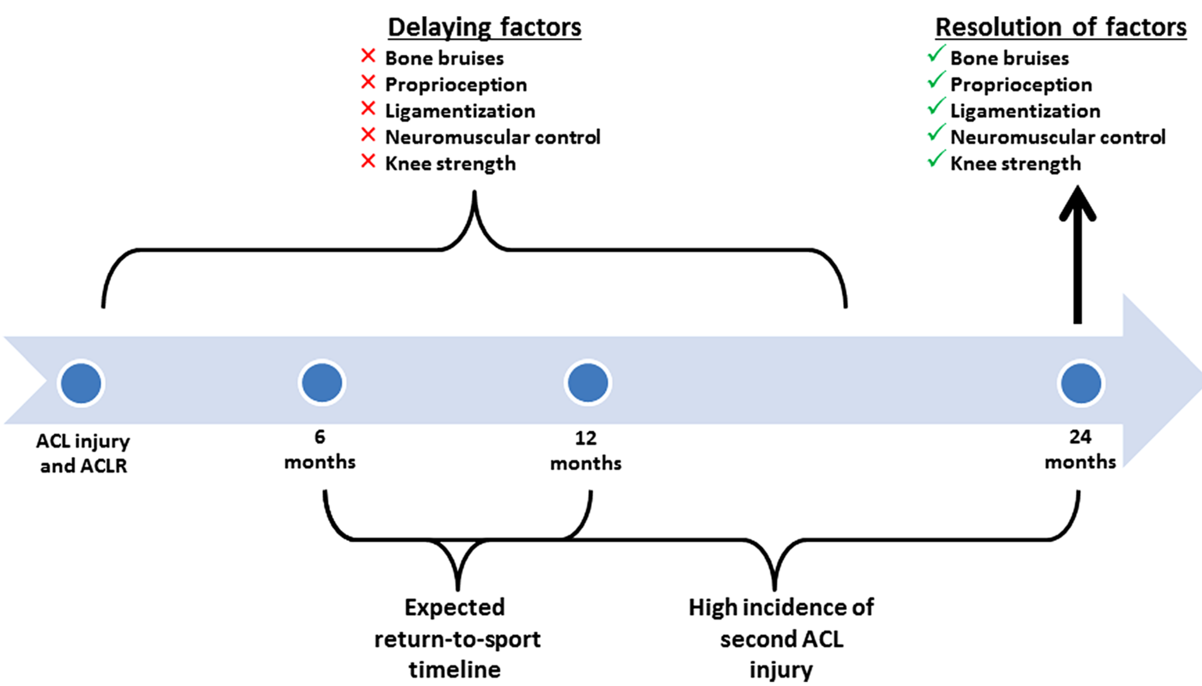


**Fig. 1** A timeline of recovery indicated in the literature and presented in this current opinion article. Recovery of baseline, or not significantly different from baseline, joint health and function is not indicated until 2 years after anterior cruciate ligament (ACL) reconstruction (ACLR). We advocate significantly delaying returning to sport to at least 2 years after ACLR

depending on the athlete's potential, their future long-term career. However, the current approach of early accelerated rehabilitation programs and the expected timeline to recovery of 6–12 months is deleterious because the athlete is not completely recovered, which predisposes them to an increased risk for a second ACL injury. The young active athlete who attempts to resume sports participation at the same competitive level has a nearly one in three chance of going on to experience a second ACL injury within the first or second year post-ACLR. Therefore, the evidence advocates that these athletes delay a return to sports for 2 years to mitigate the unacceptably high risk for a second ACL injury, especially in those aged <20 years.

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**Compliance with Ethical Standards**

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