Review Article

Return to Play Following Anterior Cruciate Ligament Reconstruction

Michael B. Ellman, MD
Seth L. Sherman, MD
Brian Forsythe, MD
Robert F. LaPrade, MD, PhD
Brian J. Cole, MD, MBA
Bernard R. Bach, Jr, MD

Abstract

In athletes, significant advances in anterior cruciate ligament reconstruction techniques and rehabilitation have led to improved surgical outcomes and increased expectations for return to play. Although an expeditious return to sport has become an achievable and often realistic goal, the factors that most influence safe, timely, and successful return to play remain unknown. The literature offers mainly anecdotal evidence to guide the team physician in the decision-making process, with a paucity of criteria and consensus guidelines available to help determine return to sport. Attempts have been made to introduce criteria-based progression in the rehabilitation process, but validation of subjective and objective criteria has been difficult. Nevertheless, several pertinent factors in the preoperative, intraoperative, and postoperative periods may affect return to play following anterior cruciate ligament reconstruction. Further research is warranted to validate reliable, consensus guidelines with objective criteria to facilitate the return to play process.

From the Steadman Philippon Research Institute, Vail, CO (Dr. Ellman and Dr. LaPrade), University of Missouri, Columbia, MO (Dr. Sherman), and Rush University Medical Center, Chicago, IL (Dr. Forsythe, Dr. Cole, and Dr. Bach).

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Return to Play–Expectation Compared With Reality

Anterior cruciate ligament (ACL) tears are one of the most common knee ligament injuries in athletes, accounting for up to 64% of all knee injuries in cutting and pivoting sports.[1] For athletes who wish to return to play (RTP), the benchmark for treatment of ACL rupture is surgical reconstruction. The purpose of an ACL reconstruction (ACLR) is to eliminate functional instability, thereby reducing the risk of subsequent injury to the menisci and articular cartilage.[2] In athletes, advances in ACLR and rehabilitation have led to improved outcomes and heightened expectations for successful and expeditious RTP.

Previous studies, however, suggest that a discrepancy exists between expectations and RTP in athletes, with RTP rates ranging from 60% to 80% in a variety of different sports[3-7] (Table 1). Ardern et al[4] evaluated 48 studies and 5,770 patients in a systematic review and meta-analysis on RTP following ACLR. Overall, 82% of patients returned to sport, but only 63% were participating in their preinjury sport and 44% had returned to competitive sport. Furthermore, existing high-level literature fails to clearly and consistently define RTP rates.[17,18] In a systematic review of 49 level I and II studies of RTP guidelines following ACLR, the description of permission/allowance to return to sport was highly variable and poor; only five studies reported whether patients were able to successfully RTP, and 24% of studies failed to report when patients returned without restrictions.[19] Most of these studies also fail to account for variables such as age, gender, timing during the season, the existence of concomitant injuries or persistent knee symptoms, family issues, and contract-specific issues.

One of the greatest obstacles in establishing consistent RTP rates involves inconsistencies in defining safe RTP. Precise and consistent terminology is essential, yet previous studies differ in their definition of safe and successful RTP.[3-7] For example, if the athlete has returned to play, has he or she returned to the same level of competition, and if so, has his or her performance suffered? How does the athlete's mental state impact RTP? What is the athlete's risk for reinjury following return? To date, few studies attempt to answer these questions, making the RTP decision-making process challenging. Although attempts have been made to introduce criteria-based progression into the rehabilitation process, validation of subjective and objective criteria for RTP has been difficult.[20,21]

To answer many of these questions based on the best available evidence in the literature (ie, mostly level IV and level V evidence), the most important preoperative, intraoperative, and postoperative principles that affect RTP after ACLR are presented in Table 2.

Preoperative Factors Affecting Return to Play

Following the diagnosis of an ACL tear, preoperative rehabilitation should begin immediately to expedite RTP (Table 3). Preoperative rehabilitation is designed to reduce pain, inflammation, and swelling, restore normal range of motion, improve neuromuscular control, normalize gait, and prevent muscle atrophy.[22] Knees reconstructed in the acute setting, before regaining full range of motion (ROM), are at greatest risk for stiffness and arthrofibrosis because the best predictor of postoperative ROM is preoperative ROM.[23] Loss of motion can be detrimental to the outcomes of primary ACLR, leading to decreased and delayed athletic functional performance, altered gait and running patterns, and increased patellofemoral contact pressures with subsequent joint degeneration.[24] The optimal timing for surgery should be after the athlete has regained full ROM, typically between 1 and 4 weeks postinjury, or as early as 2 to 3 days postinjury with an aggressive preoperative rehabilitation program and/or early knee aspiration of hemarthrosis to improve ROM, stimulate early quadriceps function, and improve pain control.[23]

Intraoperative Factors Affecting Return to Play

Anatomic Graft Position and Graft Tensioning

The anatomic position of the femoral and tibial tunnels is perhaps the most critical factor that leads to improved patient outcomes following ACLR.[25] The surgeon must place a strong emphasis on anatomic tunnel placement and appropriate graft tensioning to ensure optimal graft isometry and function.[26]

Graft Choice and Return to Play

The ideal graft is one that allows for secure fixation, has minimal morbidity, and allows for early, safe, postoperative rehabilitation and timely RTP.[27] The options for available grafts fall into two general categories: autograft and allograft. For autograft reconstruction, there are multiple options for use, but the most common are bone-patellar tendon-bone (BTB), hamstring, and quadriceps tendon.

Many studies demonstrate predictable and safe outcomes and timely RTP using BTB autograft in elite athletes.[28-31] The advantages of BTB autograft include excellent graft strength/stiffness and stable interference screw fixation, allowing for bone-to-bone healing within the ACL tunnels.[29,31] In animal studies, bone

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graft incorporation has been reported to occur as early as 6 weeks postoperatively, in comparison with 8 to 12 weeks with hamstring (ie, soft tissue) autograft.[32] Whereas incorporation of the graft does not equate to maturation, earlier graft incorporation may allow for more aggressive rehabilitation protocols and a more rapid RTP.

In a prospective, randomized study by Wipfler et al,[33] the authors compared hamstring autograft with BTB autograft and reported no significant objective differences between the two groups at long-term follow-up. With isokinetic testing, quadriceps strength was close to normal (96%) in both groups, but hamstring strength was predictably lower in the hamstring tendon group (100.3% versus 95.1%). Kneeling, knee walking, and single-leg hop tests showed better results in the hamstring group,[33] revealing the potential morbidity of the BTB group in athletes who require increased patellofemoral contact forces, such as wrestlers. Other studies, however, have shown that peak flexion torque at high angles is reduced after hamstring autograft harvest compared with BTB harvest,[34,35] bringing into question the use of hamstring autograft in athletes who participate in sports that require cutting or jumping activities. Leys et al[36] demonstrated a higher retear rate with hamstring autograft (17%) compared with BTB autograft (8% [$P < 0.07$]); these findings have been corroborated by others.[37]

In patients with genu recurvatum (ie, hyperlax female gymnasts), Goldblatt et al[38] and Ghodadra et al[39] have shown that hamstring autografts tend to stretch out over time, whereas BTB autografts stretch less. Studies have also demonstrated that smaller hamstring autografts (<8 mm in diameter)[40,41] in younger patients (<20 years)[41,42] are associated with worse clinical outcomes and with a greater chance for failure and revision; the use of larger hamstring autografts (>8 mm) is recommended to optimize outcomes. Finally, athletes, such as skiers and soccer players, require the medial knee stabilizers for sport-specific tasks, potentially making hamstring autografts less of an ideal graft choice in this population. Therefore, given that decreased hamstring strength (relative to quadriceps strength) has been reported as a risk factor for ACL injury,[43] and that a greater percentage of patients who underwent reconstruction with BTB autografts returned to sport compared with patients with hamstring autografts,[44] the authors prefer to use BTB autograft in this population.

The use of allograft for ACLR is controversial in the young athlete. Although decreased donor site morbidity and earlier return of dynamic muscle strength may facilitate functional return, slower graft ligamentization requires a prolonged period of protection to prevent catastrophic graft failure.[27,45,46] Clinical studies report increased rates of allograft failure compared with autograft in the young, active population;[28-31] in one study, allograft failure rates exceeded 40%.[28] In a study of ACLR in military cadets, 33% of athletes with allograft ACLR experienced graft failure at 1-year follow-up (compared with 2% with autograft), while more than half of the allograft patients experienced graft failure at 2-year follow-up (compared with only 6% in the autograft group).[28] However, these studies did not standardize for graft processing (ie, irradiation), surgical technique, and rehabilitation protocols, and a specific patient age at which allograft failure rates are equivalent to autograft failure rates is currently unknown.[28-31] Higher-quality trials are necessary to determine the safety and efficacy of allograft ACLR in the young, active population. At present, the authors do not recommend routine use of allograft ACLR in this population based on concerns for higher graft failure and the requirement for delayed RTP.

Postoperative Factors Affecting Return to Play

The importance of a strict and reproducible rehabilitation program is paramount to the RTP process; several authors have reported that RTP is more dependent on the rehabilitation program than on the technique or the graft choice used intraoperatively.[47,48] Shelbourne and Nitz[49] were the first clinicians to describe an accelerated rehabilitation program for athletes following ACLR. The main differences between traditional and accelerated programs are the rate of progression through the various phases of rehabilitation and the period of time recommended before return to sports.[22,45] Beynnon et al[50] reported that rehabilitation with an accelerated protocol (ie, 19 weeks) compared with a non-accelerated protocol (ie, 32 weeks) resulted in no differences in subjective and objective outcomes following ACLR with patellar tendon autograft, thus spurring the movement toward accelerated rehabilitation programs for athletes. A modified version of the Shelbourne and Nitz[49] accelerated protocol, as described by Wilk et al,[45] has been adopted at the senior authors' institution and is presented in Table 3. Prior to advancement to the next phase, specific criteria must be met with regard to ROM, strength, neuromuscular control, proprioception, functional tests, clinical examination, endurance, and subjective knee scores. Table 4 summarizes criteria to permit RTP based on the authors' experience with a large number of reconstructions in high-level athletes. Unfortunately, few of these criteria have been validated in the literature.

Table 1

Sport-specific Return to Play Rates Following Anterior Cruciate Ligament Reconstruction

Study	No. of Patients	Study Design (Level of Evidence)	Sport	Graft Type	% RTP	Comment
Brophy et al[8]	100	Cohort (III)	Soccer	Variable	72% RTP	Older athletes and females less likely to RTP
Mascerenhas et al[9]	46	Case-control (III)	Very strenuous (soccer, basketball) compared with strenuous (skiing, tennis)	23 BTB 23 HS	Return to sport: 74% BTB 70% HS Return to preinjury level: 57% BTB 44% HS	HS grafts associated with higher subjective scores, improved extension, and decreased risk of OA
McCullough et al[10]	147	Cohort (III)	Collegiate and high school American football	Not specified	Return to sport: 63% high school 69% collegiate Overall 43% RTP at same level of competition	Psychological factors (ie, fear of reinjury) most common cause of failure to RTP
Namdari et al[11]	18	Case series (IV)	WNBA	Variable	79% RTP	No significant change in performance following ACLR
Shah et al[7]	49	Case series (IV)	NFL	47 BTB 2 HS	63% RTP	Average time to RTP = 10.8 mo. Increased experience correlates with increased chance for RTP
Carey et al[6]	33	Prospective cohort (II)	NFL running backs and wide receivers	Not specified	78% RTP	Average time to RTP = 55.8 wk. Of returning players, performance rating decreased by approximately 33% after RTP

(*continued*)

ACL = anterior cruciate ligament, ACLR = anterior cruciate ligament reconstruction, BTB = bone-patellar tendon-bone autograft, HS = hamstring, IKDC = International Knee Documentation Committee, NBA = National Basketball Association, NFL = National Football League, OA = osteoarthritis, PER = player efficiency rating, RTP = return to play, WNBA = Women's National Basketball Association

To date, the effect of an accelerated rehabilitation protocol in patients undergoing hamstring ACLR has not been demonstrated in a controlled study, yet Fujimoto et al[51] reported this protocol may lead to significant graft laxity over time. Further studies are warranted to elucidate the effects of an accelerated program following ACLR using hamstring grafts.

It is important to remember that although the protocol provided in Table 3 addresses a timeline for progression, each patient differs in terms of functional status, and little evidence supports the use of time as a basis for progression after ACLR.[52] Furthermore, this protocol is based largely on the authors' experiences and lower level evidence rather than high-level studies, given the lack of level I and level II evidence in the literature on RTP following ACLR. Therefore, these time periods are simply guidelines, and progression through each stage should proceed via both patient-specific functional advancement and the time necessary for biologic healing of the graft.

Sport-specific Training and Return to Play

Assuming the criteria listed in Table 4 are met, the athlete may return to limited practice, and if no setbacks are encountered, the athlete may return to full activity

Table 1 (*continued*)

Sport-specific Return to Play Rates Following Anterior Cruciate Ligament Reconstruction

Study	No. of Patients	Study Design (Level of Evidence)	Sport	Graft Type	% RTP	Comment
Busfield et al[5]	27	Case series (IV)	NBA	Not specified	78% RTP	Average time to RTP = 325 ± 81 d; PER decreased by >1 point in 44% of players who returned to play
Roos et al[12]	86	Case series (IV)	Soccer	BTB	18% RTP at 7-yr follow-up	Poor RTP rates and Lysholm scores in soccer players with ACL injuries
Fabbriciani et al[13]	18	Case series (IV)	Rugby	Doubled HS	100% RTP at 6 mo	Normal or near-normal Tegner, IKDC scores, KT-1000 in 90% of cases
Plancher et al[14]	75	Case series (IV)	Bicycling, running, skiing, tennis	BTB	Bicycling: 100% RTP Jogging: 86% RTP Skiing: 91% RTP Tennis: 80% RTP	Mean time to RTP: Bicycling = 4 mo Jogging = 9 mo Skiing = 10 mo Tennis = 12 mo
Ardern et al[15]	503	Case series (IV)	Australian football, basketball, netball, soccer	HS	33% RTP at full competition 67% no RTP at competitive levels at 1 yr postoperative	Of those who had not returned to sport, 47% intended RTP in future
Brophy et al[16]	94	Case-control (III)	Collegiate football/ NFL	Not specified	History of isolated meniscectomy reduced length of career more than isolated ACLR	History of combined meniscectomy with ACLR more detrimental to athlete's durability than ACLR alone

ACL = anterior cruciate ligament, ACLR = anterior cruciate ligament reconstruction, BTB = bone-patellar tendon-bone autograft, HS = hamstring, IKDC = International Knee Documentation Committee, NBA = National Basketball Association, NFL = National Football League, OA = osteoarthritis, PER = player efficiency rating, RTP = return to play, WNBA = Women's National Basketball Association

without limitations. Importantly, athletes are likely more susceptible to reinjury as they fatigue, elucidating the importance of incorporating a program of endurance exercises before full RTP.[53] In a systematic review by Harris et al,[19] the authors reported that 51% of studies allowed RTP without restrictions at 6 months postoperatively, while 86% of studies permitted RTP at 9 months. The authors prefer to wait at least 6 months before allowing RTP without restrictions to allow for graft healing and to decrease the risk for early graft failure, despite limited evidence for a strict timeline for RTP.

Objective Criteria as Guidelines for Return to Play

Few objective validated testing measures are available to guide the physician for the RTP decision-making process. For example, Harris et al[19] reported on 49 level I and II studies; 90% and 65% of the studies failed to use objective criteria or any criteria, respectively, to permit return to sport. Barber-Westin and Noyes,[52] in a systematic review of 264 studies, reported that 105 studies (40%) failed to provide any measures for RTP after surgery, and only 35 studies (13%) included objective criteria that consisted of the categories of muscle strength or

Table 2

Factors Affecting Return to Play in Athletes Following ACLR

Preoperative	Intraoperative	Postoperative
Age	Graft choice	Accelerated rehabilitation protocol
Preoperative rehabilitation	Autograft versus allograft	Acute postoperative period
Full knee extension	Hamstring versus BTB	Cryotherapy
Neuromuscular control		Electrical stimulation
		Joint compression
		± Biofeedback
		± Knee brace
		Weeks 2-10
		Neuromuscular control
		Closed kinetic chain exercises
		± Open kinetic chain exercises
		Weeks 10-22
		Knee flexion and extension strength
		Core strength
		Postural stability/proprioceptive training
		Sport-specific training
		Psychological factors

ACLR = anterior cruciate ligament reconstruction, BTB = bone-patellar tendon-bone autograft

thigh circumference, general knee examination, single-leg hop tests, Lachman rating, or validated questionnaires. These findings demonstrate a lack of objective assessment before release to athletics.

One of the major obstacles in determining objective RTP criteria is identifying the criteria purpose. For example, should criteria be used to determine the athlete's physical ability to RTP (often the athlete's preference), or should criteria be used to determine the athlete's safety following RTP (often the surgeon's preference)? These criteria remain undefined in the literature. In addition, an athlete may not be able to RTP, despite passing all objective criteria, because of his or her mental state and/or expectations, further challenging the use of objective criteria to help determine RTP. In a review of nearly 6,000 patients after ACLR, only 44% of patients were able to return to competitive sport, despite the fact that 90% of patients had normal or nearly normal function using objective outcome scores and that 85% of patients had normal or nearly normal function on the basis of activity measures, such as the International Knee Documentation Committee subjective knee evaluation form.[4]

Nevertheless, several studies have attempted to define objective criteria to guide RTP. One measure is hop testing, a functional rehabilitation test that may signal the capacity for successful RTP.[54] The most common hop tests used in clinical practice are the single-leg hop for distance, the single-leg triple hop for distance, the single-leg timed hop, the single-leg crossover hop for distance, and the vertical jump test.

In a cohort study of patients after ACLR using BTB autograft, Hopper et al[55] suggested using a specific series of hop tests to assess functional recovery to resume play. Using a score of ≥85% as a criterion for normative limb symmetry, patients achieved passing scores in a 6-minute timed hop at week 18, in the stair hop and the vertical hop at week 26, and in the crossover hop at week 39, suggesting that these criteria may be used to assess RTP in athletes.[55] As noted, the crossover hop was not achieved until week 39 (almost 10 months postoperatively), but several athletes have successfully returned to sport earlier than this timeline suggests.

In a study by Yosmaoglu et al,[56] the authors theorized about a series of hop tests that would provide a reliable and valid performance-based outcome measure following ACLR. Brosky et al[57] reported a high intrarater reliability using functional hop tests, the Biodex isokinetic dynamometer, and the KT-1000, suggesting these tests may be used in combination to evaluate progress. Wilk et al,[58] in combining three different measures, reported a positive correlation between isokinetic knee extension peak torques, subjective knee scores, and three different single-leg hop tests (ie, hop for distance, timed hop, and crossover triple hop), suggesting that these tests may be used in conjunction to predict progression and RTP.

Paterno et al[59] and Hewett et al[60] first reported that dynamic valgus observed on drop vertical tests is a significant risk factor for ACL injury, reinjury, and contralateral ACL injury, and McLean et al[61] described a method of measuring dynamic valgus in basketball players using two-dimensional video analysis. The authors suggested that optimizing neuromuscular control of the hip and knee following ACLR, via a decrease in dynamic valgus, may decrease the risk of knee injury following RTP.[59]

During rehabilitation, hop testing provides a reliable and valid outcome measure that replicates the demands of high-level activities; however, it may not be sensitive enough to identify some functional limitations associated with untested multiplanar movements.[62,63] Currently, the use of hop tests or dynamic valgus measures is institution-specific and has yet to be adopted as consensus guidelines. No one single outcome criterion has been correlated with successful RTP. Most clinicians prefer to use a combination of functional, clinical, and subjective testing to determine readiness to RTP. At the senior authors' institution, a functional sports assessment has been created based on the best available literature, yet it is largely based on level IV and V evidence (Table 5). Prior to RTP, an athlete must complete the functional sports assessment; the team physician then determines readiness for RTP. Unfortunately, given the lack of a specific biologic time point for safe RTP, the head team physician often has difficulty making this determination. At the time of clearance, a conversation between the team physician and the athlete, family, and trainer should address several of these unknown variables, including the risk of reinjury despite being cleared to play, the biologic healing that will continue to progress after RTP, and the importance of persistent rehabilitation to enhance neuromuscular control beyond the first year after surgery.

Variations in Rehabilitation

Variations to the provided standard rehabilitation protocol exist because of a variety of factors. Patient-specific factors play a role in the progression of rehabilitation, such as motivation or desired activity level, timing of injury, contract or family issues, and concomitant injuries/surgeries. The age of the athlete, the stage of an athlete's career, the time of the season, and the level of athletics (eg, recreational, professional) all play a significant role in the rehabilitation and decision-making process. More specifically, concomitant injuries are common in athletes with ACL tears and have the potential to profoundly delay the postoperative course. Brophy et al[16] reported that a history of meniscectomy, but not ACLR, shortens the expected career of a professional football player, and a combination of ACLR with meniscectomy may be more detrimental to an athlete's durability than ACLR alone.

Functional Bracing After Return to Sport

The role for functional ACL braces during and after return to sport remains controversial. The general trend is to use braces during sports for at least the first year after surgery; however, the literature behind this is lacking.[48] Studies show that the use of a brace can improve early coordination and jumping mechanics, while providing a positive psychological effect.[64] Furthermore, braces have been shown to be effective in preventing recurrent ACL injury in skiers.[65] In contrast, other studies have shown no increase in stability or in speed to RTP, with some studies even suggesting that bracing may potentially decrease speed and turning quickness.[66,67] Despite these controversies, the authors recommend use of a functional brace during the acute transition back to sports and permanent use in skiers during ski-related activities.

Psychological Factors Affecting Return to Play

Perhaps the most important factor in determining an athlete's RTP is his or her psychological state. Each athlete varies in his or her subjective sense of stability, confidence, and comfort with RTP. Gobbi and Francisco[68] prospectively analyzed the effects of various subjective scoring systems on RTP after ACLR using either patellar tendon or hamstring grafts. Using the International Knee Documentation Committee subjective knee form and the Lysholm, Noyes, and Tegner subjective knee evaluation scales, the authors found no significant differences between athletes who returned to sports and athletes who did not return to sports. However, in a psychiatric questionnaire, the authors found significant differences between the two groups, and along with other clinicians,[4,15,69,70] have suggested that psychological factors significantly affect RTP in athletes. Two other validated methods to identify each patient's psychological status postoperatively include the Tampa Scale of Kinesiophobia[71] and the ACL-Return to Sport after Injury scale;[72] however, these methods are not routinely used.

Table 3

Accelerated Rehabilitation Protocol Following Anterior Cruciate Ligament Reconstruction With BTB Autograft

Phase	Goals	Brace/Modalities	Exercises
Preoperative rehabilitation	Communicate expectations Normalize ROM Reduce inflammation and edema Eliminate antalgic gait	Sleeve ± knee brace to reduce swelling WBAT with or without crutches Cryotherapy Elevation Electrical stimulation	Ankle pumps, straight leg raises ROM: Passive knee ROM from 0°; flexion as tolerated Strengthening: CKC exercises (mini-squats, lunges, step-ups) NM/Proprioception: Eliminate quad avoidance gait, joint repositioning exercises
Phase I: Immediate postop phase = days 1-7	Restore full passive knee extension Diminish joint swelling/pain Restore patellar mobility Reestablish quadriceps control Restore ambulation	Sleeve versus knee brace locked at full extension for ambulation, unlocked for sitting Strengthening: CKC exercises (mini-squats, lunges, step-ups) WBAT Cryotherapy Elevation Electrical stimulation	Ankle pumps, straight leg raises ROM: Full extension to 90° passive flexion (by POD 5) NM/Proprioception: POD 4-7: ± OKC passive/active joint repositioning at 90°, 60°
Phase II: Early phase = weeks 2-4	Decrease pain and swelling Full knee extension by 2 weeks Restore NM/proprioception control Normalize patellar mobility	± Knee brace WBAT without assist by POD 10 Electrical stimulation	Ankle pumps, straight leg raises, patellar mobilization ROM: Progress through passive, active, and resisted ROM as tolerated Strengthening: CKC (0°-45°); extension board and prone hang with ankle weights (up to 10 lb); no restrictions to ankle/hip strengthening NM/Proprioception: OKC passive/active joint repositioning, CKC repositioning during squats/lunges, squats on tilt board Stationary bike with no resistance for knee flexion

(continued)

BTB = bone-patellar tendon-bone autograft, CKC = closed kinetic chain, NM = neuromuscular, OKC = open kinetic chain, POD = postoperative day, ROM = range of motion, WBAT = weight bearing as tolerated

Therefore, in an athlete with a healed graft and a fully rehabilitated knee, psychological factors, such as fear of reinjury or poor performance, should not be overlooked because they may prevent a return to the playing field. Multiple studies have reported that fear of reinjury, rather than clinical findings of instability or pain, is the single greatest reason for failure to RTP.[15,73] To date, however, a single, validated psychological tool to assess a patient's psychological state is not used clinically.

Sport-specific Outcomes Following ACLR

The Multicenter Orthopaedic Outcomes Network database allows for the analysis of sport-specific outcomes and factors influencing RTP after ACLR. Brophy et al[8] analyzed factors influencing RTP in soccer and reported that 72 of 100 soccer athletes (72%), with a mean age of 24.2 years, returned to soccer; however, only 36% of the returnees were still playing at 7-year follow-up, suggesting that continued participation declines over time. Based on multivariate analyses, RTP was less likely in older athletes and females, and graft choice had no effect on RTP.[8] In another study, McCullough et al[10] retrospectively analyzed the percentage of high school and collegiate American football players for RTP at their previous level of competition. Of 147 athletes, RTP rates were similar (63% and 69% in high school and collegiate athletes, respectively), and both rates

Table 3 (*continued*)

Accelerated Rehabilitation Protocol Following Anterior Cruciate Ligament Reconstruction With BTB Autograft

Phase	Goals	Brace/Modalities	Exercises
Phase III: NM control phase = weeks 4-10	Restore full ROM Improve strength Enhance proprioception, balance, and NM control Improve muscular endurance Restore confidence Add core strengthening exercises	—	ROM: Self ROM 4-5 times daily with emphasis on 0° passive extension; passive ROM 0°-125° at 4 wk Strengthening: Increase closed chain activities to 0°-90°; add core strengthening exercises, add side lunges, pulley weights, bands, stair stepper, bicycle NM/Proprioception: Tilt board squats (perturbation), passive/active repositioning OKC, CKC repositioning on tilt board, CKC lunges, light plyometric jump training (week 8) Running at approximately 8 wk
Phase IV: Weeks 10-16	Normalize strength Enhance power and endurance Improve NM control Perform selected sport-specific drills	—	ROM: Full active and passive Strengthening: Advance as tolerated, CKC, increase resistance NM/Proprioception: Advance plyometrics as tolerated Initiate running program, light sports program (eg, golf) Initiate agility training at week 14 (figures-of-eight, cutting drills, etc) Begin to wean from formal supervised therapy + home exercise program

BTB = bone-patellar tendon-bone autograft, CKC = closed kinetic chain, NM = neuromuscular, OKC = open kinetic chain, POD = postoperative day, ROM = range of motion, WBAT = weight bearing as tolerated

were lower than estimated. Based on player perception, only 43% of the players felt they were able to return at the same performance level, 27% felt they did not perform at a level attained before their ACL tear, and 30% were unable to RTP. At both levels of competition, fear of reinjury or further damage was cited by approximately 50% of the players who did not RTP.[10]

Existing studies vary with regard to the definition of RTP, the type and level of athlete, outcome measurements, and the length of follow-up (Table 1). In their systematic review, Ardern et al[4] found a significantly higher rate of reported RTP in studies with a mean follow-up of <24 months compared with studies with a mean follow-up of ≥24 months, implying that there may be a rapid decline in sports participation after 2 years. Patients who have successfully returned to sports may subsequently give up that sport or reduce their participation to a lower level over time.[74] Further research is warranted to identify pertinent factors and sport-specific outcomes for RTP following ACLR.

Risk of Reinjury Following ACLR

One of the greatest concerns with RTP is the risk of reinjury to the ipsilateral reconstructed graft or to the contralateral native ACL. Graft re-rupture rates after RTP range from 5% to 25%; higher rates are found in younger athletes involved in cutting or pivoting sports compared with athletes who participate in straight-line activities or who are jumpers.[24,30] In a systematic review, Wright et al[75] reported an overall risk of

Table 4

Criteria to Progress Through Phases of Accelerated Return to Play Protocol

Phases	Criteria for Progression
I	Postoperative days 0 to 7 RICE = rest, ice, compression, elevation Begin focus on regaining full extension
II	Quadriceps control (ability to perform SLR) Full passive knee extension Passive ROM 0°-90° Good patellar mobility Minimal joint effusion Independent ambulation
III	Active ROM 0°-115° Quadriceps strength ≥60% of contralateral side Unchanged KT-1000 values (+1 or less) Minimal to no joint effusion No joint line or PF pain
IV	Subjective Noyes knee scoring ≥80 points AROM 0°-125° Quadriceps strength ≥80% of c/l side Knee extensor:flexor ratio 70%:75% No change in KT-1000 values (<3 mm) No pain/effusion Negative Lachman, negative pivot shift tests Hamstring strength equal b/l, hamstring:quadriceps ratio 66%:75% Single-leg hop test (≥80% of c/l leg)
V: RTP phase	Subjective: Lysholm >75, SANE >75, no sense of instability, normal ADLs, Noyes scoring system >90 Full AROM Exam: Negative Lachman, negative pivot shift tests KT-1000 <3 mm c/l side NM testing: Quadriceps atrophy <2 cm, quadriceps strengthening ≥85% than c/l side, hamstring 100% of c/l side, quadriceps torque:body weight ratio ≥55%, hamstring:quadriceps strength ratio ≥70% Single-leg press ≥90% of normal, single-leg squat >60° Functional tests: vertical jump test, single-leg hop distance, and timed single-leg hop over 20 ft ≥85% of c/l side

ADL = activities of daily living, AROM = active range of motion, b/l = bilateral, c/l = contralateral, NM = neuromuscular, PF = patellofemoral, ROM = range of motion, RTP = return to play, SANE = single assessment numerical evaluation, SLR = straight leg raise

hamstring or BTB graft rupture of 5.8% (range, 1.8% to 10.4%) at a minimum 5-year follow-up and an overall rate of contralateral ACL rupture of 11.8% (range, 8.2% to 16%). The exact time at which the risk of reinjury to the ipsilateral knee (ie, ACL graft) is equal to injury to the contralateral ACL is unknown. As stated, perhaps the greatest risk of graft failure is the use of allograft in young patients,[76] particularly within the first year of reconstruction,[28] and there is a trend toward a higher failure rate for hamstring (secondary to stretching or retear) compared with BTB autograft.[36] Therefore, many surgeons prefer to use BTB autograft to minimize the risk of reinjury in young athletes.

Although older athletes have a lower rate of return to their preinjury sport,[3] younger athletes (<25 years) are at an increased risk for reinjury and revision surgery.[29,77] Bourke et al[78] reported that male gender and a positive family history of ACL injury were associated with an increased risk of ACL graft rupture. Paterno et al[59] identified specific biomechanical predictive factors for reinjury, including dynamic valgus with the vertical drop test, valgus malalignment, greater asymmetry in internal knee extensor moment at initial contact, increased hip rotation moment, and a deficit in single-leg postural stability of the involved limb (measured by the Biodex stability system). With regard to the timing of RTP, Shelbourne et al[79] found no difference in graft rupture rates in patients who returned to sport before and after 6 months following surgery; their findings were corroborated by Glasgow et al.[80]

Table 5

Functional Sports Assessment as an Aid for Determining Return to Play[a]

Activity	Dynamic Assessments
Hop testing (video monitoring)	Single-leg hop: percentage of distance of involved compared with noninvolved Triple hop: percentage of distance of involved compared with noninvolved Crossover hop: percentage of distance of involved compared with noninvolved 6-minute minute timed hop: percentage of time of involved compared with noninvolved
Single-leg squat (15 points possible)	Absence of valgus and Trendelenburg gait Avoids patella extending past toes Upright trunk flexion Constant motion Knee flexion between 60° and 0°
Lateral agility and pivoting × 2 min (40 points possible)	Knee flexion ≥30° at landing Absence of valgus Lands within boundaries Landing phase is unilateral and <1 s Maintains upright trunk
Drop to jump (23 points possible)	Maintains upright trunk, lateral trunk Absence of excessive tibial rotation, shoulder-width stance Absence of valgus Symmetric landing Absence of Trendelenburg gait Symmetric knee height at apex
Deceleration (12 points possible)	Knee flexion between 60° and 0° Knees behind toes Absence of valgus Absence of hesitancy on approach Landing phase is <1 s Maintains upright trunk flexion
Total possible score	90 points for above four tasks; no set "passing test score." Goal = at least 85% of the total score of the four dynamic tasks and of the uninvolved LE for the hop tests.

[a] Prerequisites for testing include the ability to perform the following: cutting and pivoting, unilateral hopping, 10 single-leg squats or forward step-downs without compensation, and pain consistently below 3/10 with activity.
LE = lower extremity

With regard to ACL injury to the contralateral knee, recent data suggest that if athletes fail to achieve full strength and neuromuscular control before RTP from their index surgery, the contralateral knee is at increased risk of an ACL rupture.[81] In addition, female gender, a positive family history, a return to preinjury sport, and an ACLR with a patellar graft have been identified as risk factors for injury to the contralateral knee,[80,81] although there are also studies that do not identify gender as a risk factor.[82]

A significant risk of injury to the menisci and cartilage is possible with continued sports participation following ACLR,[18] although this topic has been less well-defined. Overall, the variability between studies suggests that further investigation into the risk of reinjury to the ipsilateral graft, the contralateral ACL, and other structures in the knee is still required.

Summary

Return-to-play decision making is a challenging and often stressful process for the team physician. Unfortunately, there remains a paucity of objective criteria and consensus guidelines to facilitate the decision-making process, and the time required to return an athlete to play with an equal or lesser chance of reinjury to the reconstructed knee compared with the contralateral knee remains unknown. Perhaps the most important, yet overlooked factor in determining an athlete's RTP is his or her psychological state; the fear of reinjury has been found to play a major role in preventing return to sport. Further research is warranted to validate reliable, consensus guidelines with both subjective and objective criteria before allowing an athlete to RTP.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 35, 38, and 50 are level I studies. References 6, 19, 23, 25, 28, 29, 32, 33, 36, 37, 44, 46, 55-57, 59, 60, 62, 63, 68, 69, 75, 79, and 82 are level II studies. References 3, 4, 8-10, 16, 21, 30, 31, 34, 39-42, 51, 53, 54, 58, 64, 65, 67, 72, 77, and 80 are level III studies. References 2, 5, 7, 11-15, 52, 61, 70, 71, 73, 76, and 78 are level IV studies. References 1, 17, 18, 20, 22, 24, 26, 27, 43, 45, 47-49, 66, 74, and 81 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

1. Rishiraj N, Taunton JE, Lloyd-Smith R, Woollard R, Regan W, Clement DB: The potential role of prophylactic/functional knee bracing in preventing knee ligament injury. *Sports Med* 2009;39(11): 937-960.
2. Nebelung W, Wuschech H: Thirty-five years of follow-up of anterior cruciate ligament-deficient knees in high-level athletes. *Arthroscopy* 2005;21(6):696-702.
3. **Ardern CL, Taylor NF, Feller JA, Webster KE: Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med* 2012;40(1):41-48.**
4. **Ardern CL, Webster KE, Taylor NF, Feller JA: Return to sport following anterior cruciate ligament reconstruction surgery: A systematic review and meta-analysis of the state of play. *Br J Sports Med* 2011;45(7):596-606.**
5. Busfield BT, Kharrazi FD, Starkey C, Lombardo SJ, Seegmiller J: Performance outcomes of anterior cruciate ligament reconstruction in the National Basketball Association. *Arthroscopy* 2009;25(8): 825-830.
6. Carey JL, Huffman GR, Parekh SG, Sennett BJ: Outcomes of anterior cruciate ligament injuries to running backs and wide receivers in the National Football League. *Am J Sports Med* 2006;34(12):1911-1917.
7. Shah VM, Andrews JR, Fleisig GS, McMichael CS, Lemak LJ: Return to play after anterior cruciate ligament reconstruction in National Football League athletes. *Am J Sports Med* 2010;38(11): 2233-2239.
8. **Brophy RH, Schmitz L, Wright RW, et al: Return to play and future ACL injury risk after ACL reconstruction in soccer athletes from the Multicenter Orthopaedic Outcomes Network (MOON) group. *Am J Sports Med* 2012;40(11):2517-2522.**
9. **Mascerenhas R, Tranovich MJ, Kropf EJ, Fu FH, Harner CD: Bone-patellar tendon-bone autograft versus hamstring autograft anterior cruciate ligament reconstruction in the young athlete: A retrospective matched analysis with 2-10 year follow-up. *Knee Surg Sports Traumatol Arthrosc* 2012;20 (8):1520-1527.**
10. **McCullough KA, Phelps KD, Spindler KP, et al; MOON Group: Return to high school- and college-level football after anterior cruciate ligament reconstruction: A Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Am J Sports Med* 2012;40(11):2523-2529.**
11. **Namdari S, Scott K, Milby A, Baldwin K, Lee GC: Athletic performance after ACL reconstruction in the Women's National Basketball Association. *Phys Sportsmed* 2011;39(1):36-41.**
12. Roos H, Ornell M, Gärdsell P, Lohmander LS, Lindstrand A: Soccer after anterior cruciate ligament injury–an incompatible combination? A national survey of incidence and risk factors and a 7-year follow-up of 310 players. *Acta Orthop Scand* 1995;66(2):107-112.
13. Fabbriciani C, Milano G, Mulas PD, Ziranu F, Severini G: Anterior cruciate ligament reconstruction with doubled semitendinosus and gracilis tendon graft in rugby players. *Knee Surg Sports Traumatol Arthrosc* 2005;13(1):2-7.
14. Plancher KD, Steadman JR, Briggs KK, Hutton KS: Reconstruction of the anterior cruciate ligament in patients who are at least forty years old: A long-term follow-up and outcome study. *J Bone Joint Surg Am* 1998;80(2):184-197.
15. **Ardern CL, Webster KE, Taylor NF, Feller JA: Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: Two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med* 2011;39(3):538-543.**
16. Brophy RH, Gill CS, Lyman S, Barnes RP, Rodeo SA, Warren RF: Effect of anterior cruciate ligament reconstruction and meniscectomy on length of career in National Football League athletes: A case control study. *Am J Sports Med* 2009;37 (11):2102-2107.
17. Myer GD, Paterno MV, Ford KR, Quatman CE, Hewett TE: Rehabilitation after anterior cruciate ligament reconstruction: Criteria-based progression through the return-to-sport phase. *J Orthop Sports Phys Ther* 2006;36(6): 385-402.
18. Myklebust G, Bahr R: Return to play guidelines after anterior cruciate ligament surgery. *Br J Sports Med* 2005;39(3): 127-131.
19. **Harris JD, Abrams GD, Bach BR, et al: Return to sport after ACL reconstruction. *Orthopedics* 2014;37(2):e103-e108.**
20. Kvist J: Rehabilitation following anterior cruciate ligament injury: Current recommendations for sports participation. *Sports Med* 2004;34(4):269-280.
21. van Grinsven S, van Cingel RE, Holla CJ, van Loon CJ: Evidence-based rehabilitation following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2010;18(8): 1128-1144.
22. Wilk KE, Reinold MM, Hooks TR: Recent advances in the rehabilitation of ACL injuries, in Bach BR Jr, Provencher MT, eds: *ACL Surgery: How to Get it Right the First Time and What to Do if it Fails.* SLACK 2010:9(3):527.
23. Strum GM, Friedman MJ, Fox JM, et al: Acute anterior cruciate ligament reconstruction: Analysis of complications. *Clin Orthop Relat Res* 1990;253:184-189.
24. George MS, Dunn WR, Spindler KP: Current concepts review: Revision anterior cruciate ligament reconstruction. *Am J Sports Med* 2006;34(12):2026-2037.
25. **Fernandes TL, Fregni F, Weaver K, Pedrinelli A, Camanho GL, Hernandez AJ: The influence of femoral tunnel position in single-bundle ACL reconstruction on functional outcomes and return to sports. *Knee Surg Sports Traumatol Arthrosc* 2014;22:97-103.**
26. **Sherman SL, Chalmers PN, Yanke AB, et al: Graft tensioning during knee ligament reconstruction: Principles and practice. *J Am Acad Orthop Surg* 2012;20(10): 633-645.**
27. Frank RM: Graft selection in revision ACL reconstruction, in Bach BR Jr, Provencher MT, eds: *ACL Surgery: How to Get it Right the First Time and What to Do if it Fails.* SLACK 2010, pp 217-229.
28. **Pallis M, Svoboda SJ, Cameron KL, Owens BD: Survival comparison of allograft and autograft anterior cruciate ligament reconstruction at the United States Military Academy. *Am J Sports Med* 2012; 40(6):1242-1246.**
29. **Kaeding CC, Aros B, Pedroza A, et al: Allograft versus autograft anterior cruciate ligament reconstruction: Predictors of failure from a MOON prospective longitudinal cohort. *Sports Health* 2011;3 (1):73-81.**

30. Mehta VM, Mandala C, Foster D, Petsche TS: Comparison of revision rates in bone-patella tendon-bone autograft and allograft anterior cruciate ligament reconstruction. *Orthopedics* 2010;33(1):12.

31. Kraeutler MJ, Bravman JT, McCarty EC: Bone-patellar tendon-bone autograft versus allograft in outcomes of anterior cruciate ligament reconstruction: A meta-analysis of 5182 patients. *Am J Sports Med* 2013;41 (10):2439-2448.

32. Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF: Tendon-healing in a bone tunnel: A biomechanical and histological study in the dog. *J Bone Joint Surg Am* 1993;75(12):1795-1803.

33. Wipfler B, Donner S, Zechmann CM, Springer J, Siebold R, Paessler HH: Anterior cruciate ligament reconstruction using patellar tendon versus hamstring tendon: A prospective comparative study with 9-year follow-up. *Arthroscopy* 2011; 27(5):653-665.

34. Tadokoro K, Matsui N, Yagi M, Kuroda R, Kurosaka M, Yoshiya S: Evaluation of hamstring strength and tendon regrowth after harvesting for anterior cruciate ligament reconstruction. *Am J Sports Med* 2004;32(7):1644-1650.

35. Tashiro T, Kurosawa H, Kawakami A, Hikita A, Fukui N: Influence of medial hamstring tendon harvest on knee flexor strength after anterior cruciate ligament reconstruction: A detailed evaluation with comparison of single- and double-tendon harvest. *Am J Sports Med* 2003;31(4): 522-529.

36. Leys T, Salmon L, Waller A, Linklater J, Pinczewski L: Clinical results and risk factors for reinjury 15 years after anterior cruciate ligament reconstruction: A prospective study of hamstring and patellar tendon grafts. *Am J Sports Med* 2012;40(3): 595-605.

37. Persson A, Fjeldsgaard K, Gjertsen JE, et al: Increased risk of revision with hamstring tendon grafts compared with patellar tendon grafts after anterior cruciate ligament reconstruction: A study of 12,643 patients from the Norwegian Cruciate Ligament Registry, 2004-2012. *Am J Sports Med* 2014;42(2):285-291.

38. Goldblatt JP, Fitzsimmons SE, Balk E, Richmond JC: Reconstruction of the anterior cruciate ligament: Meta-analysis of patellar tendon versus hamstring tendon autograft. *Arthroscopy* 2005;21:791-803.

39. Ghodadra NS, Mall NA, Grumet R, et al: Interval arthrometric comparison of anterior cruciate ligament reconstruction using bone-patellar tendon-bone autograft versus allograft: Do grafts attenuate within the first year postoperatively? *Am J Sports Med* 2012;40(6):1347-1354.

40. Mariscalco MW, Flanigan DC, Mitchell J, et al: The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: A Multicenter Orthopaedic Outcomes Network (MOON) Cohort Study. *Arthroscopy* 2013;29(12): 1948-1953.

41. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE: Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy* 2012;28(4):526-531.

42. Kamien PM, Hydrick JM, Replogle WH, Go LT, Barrett GR: Age, graft size, and Tegner activity level as predictors of failure in anterior cruciate ligament reconstruction with hamstring autograft. *Am J Sports Med* 2013;41(8):1808-1812.

43. Alentorn-Geli E, Myer GD, Silvers HJ, et al: Prevention of non-contact anterior cruciate ligament injuries in soccer players: Part 1: Mechanisms of injury and underlying risk factors. *Knee Surg Sports Traumatol Arthrosc* 2009;17:705-729.

44. Aglietti P, Buzzi R, Zaccherotti G, De Biase P: Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med* 1994;22(2):211-217.

45. Wilk KE, Reinold MM, Hooks TR: Recent advances in the rehabilitation of isolated and combined anterior cruciate ligament injuries. *Orthop Clin North Am* 2003;34 (1):107-137.

46. Bhatia S, Bell R, Frank RM, et al: Bony incorporation of soft tissue anterior cruciate ligament grafts in an animal model: Autograft versus allograft with low-dose gamma irradiation. *Am J Sports Med* 2012; 40(8):1789-1798.

47. Cascio BM, Culp L, Cosgarea AJ: Return to play after anterior cruciate ligament reconstruction. *Clin Sports Med* 2004; 23(3):395-408, ix.

48. Delay BS, Smolinski RJ, Wind WM, Bowman DS: Current practices and opinions in ACL reconstruction and rehabilitation: Results of a survey of the American Orthopaedic Society for Sports Medicine. *Am J Knee Surg* 2001;14(2): 85-91.

49. Shelbourne KD, Nitz P: Accelerated rehabilitation after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 1992;15(6):256-264.

50. Beynnon BD, Uh BS, Johnson RJ, et al: Rehabilitation after anterior cruciate ligament reconstruction: A prospective, randomized, double-blind comparison of programs administered over 2 different time intervals. *Am J Sports Med* 2005; 33(3):347-359.

51. Fujimoto E, Sumen Y, Urabe Y, et al: An early return to vigorous activity may destabilize anterior cruciate ligaments reconstructed with hamstring grafts. *Arch Phys Med Rehabil* 2004;85(2):298-302.

52. Barber-Westin SD, Noyes FR: Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27(12): 1697-1705.

53. Webster KE, Santamaria LJ, McClelland JA, Feller JA: Effect of fatigue on landing biomechanics after anterior cruciate ligament reconstruction surgery. *Med Sci Sports Exerc* 2012;44(5): 910-916.

54. Noyes FR, Barber SD, Mangine RE: Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med* 1991;19(5):513-518.

55. Hopper DM, Strauss GR, Boyle JJ, Bell J: Functional recovery after anterior cruciate ligament reconstruction: A longitudinal perspective. *Arch Phys Med Rehabil* 2008; 89(8):1535-1541.

56. Yosmaoglu HB, Baltaci G, Kaya D, Ozer H: Tracking ability, motor coordination, and functional determinants after anterior cruciate ligament reconstruction. *J Sport Rehabil* 2011;20(2):207-218.

57. Brosky JA Jr, Nitz AJ, Malone TR, Caborn DN, Rayens MK: Intrarater reliability of selected clinical outcome measures following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 1999;29(1):39-48.

58. Wilk KE, Romaniello WT, Soscia SM, Arrigo CA, Andrews JR: The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *J Orthop Sports Phys Ther* 1994;20(2):60-73.

59. Paterno MV, Schmitt LC, Ford KR, et al: Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med* 2010; 38(10):1968-1978.

60. Hewett TE, Myer GD, Ford KR, et al: Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *Am J Sports Med* 2005;33(4):492-501.

61. McLean SG, Walker K, Ford KR, Myer GD, Hewett TE, van den Bogert AJ: Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *Br J Sports Med* 2005;39(6):355-362.

62. Moksnes H, Risberg MA: Performance-based functional evaluation of non-operative and operative treatment after anterior cruciate ligament injury. *Scand J Med Sci Sports* 2009;19(3):345-355.

63. Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR: Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Phys Ther* 2007; 87(3):337-349.

64. Rebel M, Paessler HH: The effect of knee brace on coordination and neuronal leg muscle control: An early postoperative functional study in anterior cruciate ligament reconstructed patients. *Knee Surg Sports Traumatol Arthrosc* 2001;9: 272-281.

65. Sterett WI, Briggs KK, Farley T, Steadman JR: Effect of functional bracing on knee injury in skiers with anterior cruciate ligament reconstruction: A prospective cohort study. *Am J Sports Med* 2006;34(10):1581-1585.

66. Beynnon BD, Good L, Risberg MA: The effect of bracing on proprioception of knees with anterior cruciate ligament injury. *J Orthop Sports Phys Ther* 2002;32(1): 11-15.

67. Wu GK, Ng GY, Mak AF: Effects of knee bracing on the functional performance of patients with anterior cruciate ligament reconstruction. *Arch Phys Med Rehabil* 2001;82(2):282-285.

68. Gobbi A, Francisco R: Factors affecting return to sports after anterior cruciate ligament reconstruction with patellar tendon and hamstring graft: A prospective clinical investigation. *Knee Surg Sports Traumatol Arthrosc* 2006;14(10): 1021-1028.

69. Everhart JS, Best TM, Flanigan DC: Psychological predictors of anterior cruciate ligament reconstruction outcomes: A systematic review. *Knee Surg Sports Traumatol Arthrosc* 2015;23(3):752-762.

70. Tjong VK, Murnaghan ML, Nyhof-Young JM, Ogilvie-Harris DJ: A qualitative investigation of the decision to return to sport after anterior cruciate ligament reconstruction: To play or not to play. *Am J Sports Med* 2014;42(2):336-342.

71. Kvist J, Ek A, Sporrstedt K, Good L: Fear of re-injury: A hindrance for returning to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2005;13:393-397.

72. Webster KE, Feller JA, Lambros C: Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport* 2008;9(1):9-15.

73. Warner SJ, Smith MV, Wright RW, Matava MJ, Brophy RH: Sport-specific outcomes after anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27(8): 1129-1134.

74. Feller J, Webster KE: Return to sport following anterior cruciate ligament reconstruction. *Int Orthop* 2013;37(2):285-290.

75. Wright RW, Magnussen RA, Dunn WR, Spindler KP: Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: A systematic review. *J Bone Joint Surg Am* 2011;93(12):1159-1165.

76. van Eck CF, Wong AK, Irrgang JJ, Fu FH, Tashman S: The effects of limb alignment on anterior cruciate ligament graft tunnel positions estimated from plain radiographs. *Knee Surg Sports Traumatol Arthrosc* 2012;20(5):979-985.

77. Hettrich CM, Dunn WR, Reinke EK, Spindler KP; MOON Group: The rate of subsequent surgery and predictors after anterior cruciate ligament reconstruction: Two- and 6-year follow-up results from a multicenter cohort. *Am J Sports Med* 2013;41(7):1534-1540.

78. Bourke HE, Salmon LJ, Waller A, Patterson V, Pinczewski LA: Survival of the anterior cruciate ligament graft and the contralateral ACL at a minimum of 15 years. *Am J Sports Med* 2012;40(9): 1985-1992.

79. Shelbourne KD, Gray T, Haro M: Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med* 2009;37(2): 246-251.

80. Glasgow SG, Gabriel JP, Sapega AA, Glasgow MT, Torg JS: The effect of early versus late return to vigorous activities on the outcome of anterior cruciate ligament reconstruction. *Am J Sports Med* 1993; 21(2):243-248.

81. Hewett TE, Di Stasi SL, Myer GD: Current concepts for injury prevention in athletes after anterior cruciate ligament reconstruction. *Am J Sports Med* 2013; 41(1):216-224.

82. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J: A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: A controlled, prospective trial. *Am J Sports Med* 2007; 35(4):564-574.