One in 5 Athletes Sustain Reinjury Upon Return to High-Risk Sports After ACL Reconstruction: A Systematic Review in 1239 Athletes Younger Than 20 Years

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Context: Anterior cruciate ligament (ACL) reconstruction (ACLR) is frequently performed in patients younger than 20 years whose goal is to return to sport (RTS). Varying reinjury rates have been reported, and the factors responsible are unclear. Studies differ with regard to age, graft type, surgical techniques, postoperative rehabilitation, RTS guidelines, and methods used to determine ACL failures.

Objective: To determine RTS rates; the effect of participation in high-risk sports, sex, and graft type on ACL reinjury rates; and whether objective test criteria before RTS correlate with lower reinjury rates.

Data Sources: A systematic review of the literature from inception to May 31, 2019, was conducted using the PubMed and Cochrane databases.

Study Selection: Studies on transphyseal ACLR in athletes <20 years old with a minimum mean follow-up of 2 years that reported reinjury rates, the number that RTS, and detailed the type of sport were included.

Study Design: Systematic review.

Level of Evidence: Level 4.

Results: A total of 1239 patients in 8 studies were included; 87% returned to sport and 80% resumed high-risk activities. Of the patients, 18% reinjured the ACL graft and/or the contralateral ACL. Nine percent of patellar tendon autografts and 15% of hamstring autografts failed (odds ratio [OR], 0.52; $P = 0.002$). Of reinjuries, 90% occurred during high-risk sports. Male patients had a significantly higher rate of ACL graft failure than female patients (OR, 1.64; $P = 0.01$). There was no sex-based effect on contralateral ACL injuries. Only 1 study cited objective criteria for RTS.

Conclusion: A high percentage of athletes returned to sport, but 1 in 5 suffered reinjuries to either knee. Male patients were more likely to reinjure the ACL graft. Objective criteria for RTS were rarely mentioned or not detailed. The need for testing of knee stability, strength, neuromuscular control, agility, and psychological measures before RTS remains paramount in young athletes.

Keywords: ACL reconstruction; return to sport; ACL reinjury; transphyseal ACL reconstruction

The rate of anterior cruciate ligament (ACL) reconstruction (ACLR) in patients younger than 20 years has increased dramatically[18,40,104]; 1 study reported a 5.7-fold increase in the rate of ACLR between 2004 and 2014 in patients aged 18 years or younger.[97] Adolescents are frequently treated with ACLR to prevent further injury to the menisci and articular cartilage and allow for return to sport (RTS).[25,28,38,49,79,100] Although variability exists in RTS rates of adolescents after ACLR,[60,63,85] several studies have reported that 90% or more returned.[26,50,75,86,95] However, there is a justifiable concern over the potential for reinjury in this population. Investigations that compared reinjury rates (to either knee) after ACLR between

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adolescent and adult cohorts have shown significantly higher rates in adolescents.[2,3,7,30,91,98,102] For instance, Webster et al[102] compared reinjury rates in patients <20 years with those ≥20 years; ACL graft rupture rates were 14% and 2%, respectively (odds ratio [OR], 6.3; $P = 0.0001$), and contralateral ACL rupture rates were 16% and 5%, respectively (OR, 3.1; $P = 0.001$).

There are many potential risk factors for reinjuries after ACLR in younger patients. Although several authors have cited age <20 years as a risk factor,[14,15,22,45,55,59,73,86,102] few have also included RTS in a multivariate analysis.[23,76] Individual studies have cited return to high-risk sports involving jumping/landing, cutting, and pivoting[37,52,71,82,102]; use of an allograft[13,27]; and neuromuscular deficiencies on landing from a jump and cutting[70,72] as other risk factors. Problems incurred when analyzing the literature in this young population include the combination of different types of ACLR techniques and grafts within studies, limited information regarding rehabilitation, detailed RTS data not provided, inclusion of only ACL revisions as failures (as is done in registry or questionnaire-based studies[3,29,30,59,60,71,73]), and inclusion of patients >20 years of age in the cohort.[1,37,46,105] For instance, 1 meta-analysis of 5 studies reported a secondary ACL injury rate of 23% in patients ≤25 years of age who returned to high-risk sports.[105] However, these 5 studies varied with regard to age, graft type, surgical techniques, postoperative rehabilitation, RTS guidelines, and methods used to determine ACL failures.

ACLR techniques for children and adolescents differ according to skeletal maturity and are generally categorized as physeal-sparing (extraphyseal and all-physeal), partial transphyseal, and transphyseal (adult reconstruction). Investigators have reported varying reinjury rates after ACLR in high school and collegiate athletic populations that usually undergo transphyseal procedures.[10,40,42,44,83,93,94] A recent systematic review of 20 studies involving 1156 patients <20 years old reported that 92% returned to sport, 13% suffered ACL graft reinjuries, and 14% tore the contralateral ACL.[48] This study combined all types of ACL techniques and grafts, with the patient age ranging from 6 to 19 years. An analysis of the effect of return to high-risk sports on reinjury rates was not performed.

To analyze a homogeneous cohort, this review systematically assessed RTS and reinjury rates in patients <20 years old after primary unilateral transphyseal ACLR. The goals were to determine (1) RTS rates, (2) the effect of resuming high-risk sports (involving jump/land, pivot, or cut maneuvers) on reinjury rates to the ACL of either knee, (3) the effect of sex and graft type on reinjury rates, and (4) whether the use of objective testing and specific discharge criteria before RTS correlates with lower reinjury rates. To our knowledge, this is the first systematic review that addresses these objectives in this population.

METHODS

Literature Search Strategy

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed in conducting this study.[54] The PubMed and Cochrane databases were searched for literature on the subject matter from the date of inception to May 31, 2019. The following key phrases and words were used: *anterior cruciate ligament pediatrics, ACL return to sport, anterior cruciate ligament children, anterior cruciate ligament reconstruction children, anterior cruciate ligament reconstruction adolescent, ACL adolescent, ACL skeletally immature*, and *ACL transphyseal*. No limits were set other than English language. All evidence levels were included. The full text was accessed if the abstract suggested that this might be a clinical study in the topic of interest. In addition, the reference lists from general review articles, systematic reviews, and meta-analyses obtained from the search were examined to find any other original research investigations not otherwise obtained.

Study Selection and Quality Assessment

To be included in the review, studies were required to be original research investigations, be published in English, include primary transphyseal ACL reconstruction in patients <20 years old, have a minimum mean follow-up of 2 years postoperatively, report the ACL graft reinjury rate, and report the percentage of patients that returned to sport postoperatively.

Exclusionary criteria were studies that (1) were non–peer reviewed; (2) included patients treated for tibial avulsion fractures; (3) included patient treated with direct ACL suture repair, partial physeal, or all-physeal sparing procedures; or (4) failed to describe the type of sport activity for any patient postoperatively. General or systematic reviews, meta-analyses, editorials, case reports, and all other off-topic articles were also excluded.

Study quality was evaluated using the Methodological Index for Non-Randomized Studies (MINORS) instrument.[90] The MINORS score is reported as a percentage of the total available points, as recommended by Wylie et al.[107] In addition, a modified Coleman score based on criteria described by Longo et al[56] was calculated for each study to achieve reproducibility and relevancy for the systematic review of ACL reconstruction in skeletally immature patients. The scores were categorized as excellent (85-100 points), good (70-84 points), fair (50-69 points), or poor (<50 points). Evidence levels of all articles as determined by the publishers were noted.

Data Extraction

The data extracted are shown in Appendix Table A1 (available in the online version of this article) and were reviewed by both authors, with agreement reached.

RESULTS

The search identified 4762 articles, of which 4754 were excluded (Appendix Table A2, available online), leaving 8 studies published between 2004 and 2018 for our review.[33,34,50,53,60,86,87,95] Because there were 2 studies from the same institution,[86,89] personal correspondence with the authors resulted in the correct combination of data that avoided

duplication. The mean MINORS score was 66% (range, 56%-75%), and the mean Coleman score was 60 points (range, 48-77 points). The quality of the studies was rated as good in 1, fair in 6, and poor in 1 study. The level of evidence was rated as level 4 in 6 studies,[33,34,50,53,60,87] level 3 in 1,[95] and level 2 in 1 study.[86]

There were 1239 patients followed for a mean 5.2 years (range, 2.0-20.6 years) (Table 1). Validated functional questionnaires were used in 6 studies (Appendix Table A3, available online). Sports or activity level rating assessments (Tegner,[17,96] International Knee Documentation Committee [IKDC],[39] or the Cincinnati Sports Activity Scale[9]) were used in 4 studies,[33,34,50,53] and nonvalidated sports activity surveys were used in 3 studies.[50,86,87,95]

Return to Sport

Overall, 1083 patients (87%) returned to any sport, of whom 994 (80%) resumed high-risk activities (Table 2). The mean time to RTS was provided in 3 studies[33,86,95] and ranged from 4.6 months[86] to 12.3 months[33] postoperatively.

Reinjuries

Failure of the ACL grafts was reported in 123 patients (10%) and ranged from 3% to 21% in each study (Appendix Table A4, available online). Of the reinjuries, 90% occurred during high-risk sports (Table 3). The time postoperatively that the ACL grafts failed ranged from 4 weeks[34] to a mean of 51 months.[60] Male patients had a significantly higher rate of failure compared with female patients (13% and 8%, respectively; OR, 1.64; $P = 0.01$). Overall, 15% of hamstring autografts and 9% of bone–patellar tendon–bone autografts failed (OR, 0.52; $P = 0.002$) (Figure 1).

Contralateral ACL ruptures were reported in 115 patients (10%) in 6 studies.[33,53,60,86,87,95] The time these injuries occurred postoperatively was only provided in 2 studies.[60,87] Of the injuries, 80% occurred during high-risk sports; however, the mechanism of these injuries (contact or noncontact) was not described in any study. There was no significant difference in the rate of contralateral ACL injury between male and female patients. Overall, 223 patients (18%) experienced either an ACL graft failure and/or rupture of the contralateral ACL. This includes 15 patients from 1 study[60] who sustained bilateral ACL tears postoperatively. Failure of either knee ranged from 3% to 34% per study (Figure 2). Subsequent operative procedures were performed in 19 patients in 5 studies (Appendix Table A5, available online).[34,50,53,87,95]

Parameters for Return to Sport

Six studies described parameters required for RTS (Table 4). Shelbourne et al[89] required 85% quadriceps strength before patients were allowed to return to team competition. Larson et al[53] recommended 90% limb symmetry index (LSI) on single-leg hop and triple hop tests, a time frame of 6 to 8 months postoperatively, and restoration of jump landing and pivoting mechanics that were not further detailed. Morgan et al[60] stated RTS was allowed when an objective assessment had been performed but did not detail the variables in this assessment. Three studies[34,50,95] provided only the time postoperatively RTS was usually allowed.

DISCUSSION

Return to High-Risk Activities and Reinjury Rates

Of 1149 patients who participated in high-risk sports before their injury, 994 (80%) returned to these activities postoperatively. Overall, 1 in 5 patients sustained a reinjury to either knee, 90% of which occurred while participating in high-risk sports. There exist many other studies that reported high reinjury rates in patients <20 years old that did not report the sport or activity level (ie, IKDC level I) patients were participating in when the ACLR failure occurred, and these could not be included in this review.[7,41,58,84,91,98,101] Therefore, the risk of sustaining an ACL reinjury during either low-risk sports or other accidents in this patient population remains elusive. Questionnaires and interviews were used in 3 studies[60,86,95] to obtain reinjury data, and these investigations reported 100 ACL graft tears in 828 patients. There is the potential for other atraumatic graft failures that would have been detected on physical examination, and it is not possible to speculate on the impact of these missing data on the true ACL failure rate in this young population.

The mechanism of reinjury was not provided for 90% of the ACL graft failures and 100% of the contralateral ACL injuries. It is unknown whether these reinjuries occurred as a result of muscle weakness, neuromuscular deficiencies, psychological problems (fear), poor aerobic fitness, fatigue, direct contact with an opponent, or other risk factors. Several authors have published extensive recommendations for future reporting of the outcome of ACLR in young patients.[5,19,24,48] We agree with Ardern et al[5] that a standardized approach is necessary to define the injury, classify preinjury and postoperative sport activity, and describe RTS outcomes.

Effect of Sex and Graft Type on Reinjury Rates

Male patients had a significantly higher reinjury rate to the ACLR knee than female patients (13% and 8%, respectively). This is in agreement with Shelbourne et al,[86] who reported that, in 528 patients <18 years old, male patients had a greater reinjury rate to the ACLR knee than female patients (10.6% and 7.4%, respectively; $P < 0.05$). Webster and Feller,[101] reporting on 354 patients <18 years old, found that male patients had a higher ACL graft rupture rate than female patients (28% and 13%, respectively; $P = 0.01$). There was no sex-based effect on the rate of contralateral ACL tears, which has also been reported in other studies of adolescents.[98,101]

The Importance of RTS Testing

One of our original goals was to determine whether studies that included objective testing and specific discharge criteria before RTS had lower reinjury rates compared with those that did not include testing. Only 2 studies cited any objective criteria for RTS,[53,89] and thus, this goal could not be achieved. We acknowledge that other investigators may have used specific

Table 1. Patient demographics (N = 1239)

Factor	n, n (%), or Mean (Range)
Sex, n	
Male	579
Female	660
Chronological age, y, mean (range)	14.9 (8.0-19.0)
Time from injury to ACL reconstruction, n	
Acute/subacute	173
Chronic	69
Not provided	997
Original ACL injury information, n	
Sport related	337
Not provided	902
Follow-up, y, mean (range)	5.2 (2.0-20.6)
Tanner staging, n	
Stage 1	5
Stage 2	17
Stage 1 or 2	15
Stage 3	73
Stage 4	9
Not done	1120
Physes, n	
Open	73
Closed	241
Not provided	925
ACL grafts, n (%)	
Bone–patellar tendon–bone autograft	730 (59)
Hamstring autograft (isolated)	409 (33)
Hamstring autograft and Telos artificial ligament	58 (5)
Hamstring allograft	32 (2)
Tibialis anterior allograft	8 (<1)
Fascia lata autograft	2 (<1)
Concurrent operative procedures, n	
Meniscectomy	124
Meniscal repair	123
Either repaired or left in situ (1 study)	73
Data regarding meniscal procedures not provided (2 studies)	930
Anterolateral ligament reconstruction (1 study[a])	33

ACL, anterior cruciate ligament.
[a]Geffroy et al[33]; indications for this procedure were not provided.

Table 2. Return-to-sport data

				Participation in High-Risk Sport, n (%)					
	Patients in Study, n			Preinjury			Follow-up		
Study	Total	Male	Female	Total	Male	Female	Total	Male	Female
Geffroy et al[33]	178	80	98	157 (88)	NP	NP	99 (56)	NP	NP
Goddard et al[34]	32	21	11	27 (84)	17 (81)	10 (91)	25 (78)	16 (76)	9 (82)
Kocher et al[50]	59	23	36	59 (100)	23 (100)	36 (100)	59 (100)	23 (100)	36 (100)
Larson et al[53]	30	14	16	30 (100)	14 (100)	16 (100)	30 (100)	14 (100)	16 (100)
Morgan et al[60]	242	138	104	220 (91)	NP	NP	131 (54)	NP	NP
Shelbourne et al[87]	16	11	5	16 (100)	11 (100)	5 (100)	16 (100)	11 (100)	5 (100)
Shelbourne et al[86,89]	624	234	390	582 (93)	NP	NP	582 (93)	NP	NP
Takazawa et al[95]	58	58	0	58 (100)	58 (100)	0	52 (90)	52 (90)	0
Total	1239	579	660	1149 (94)	123/127[a] (97)	67/68[a] (99)	994 (80)	116/127[a] (91)	66/68[a] (97)

[a]The denominators are the total number of males and females in the studies when the gender data were provided. NP, not provided.

criteria that were not included in the article. A prior systematic review of 264 studies found that only 13% listed objective criteria for RTS.[8] A battery of tests for release to full sports was recommended, including an isokinetic quadriceps and hamstrings strength assessment, 4 single-leg hop tests,[66] knee arthrometer, video drop-jump,[69] single-leg squat,[106] and a comprehensive knee examination. Since then, the issue of RTS criteria has received much attention in light of the unacceptable failure rates in young athletes cited by multiple investigations.[7,19,41,47,58,84,91,98,101] In 2016, Ardern et al[5] presented consensus statements regarding recommendations for RTS decision making from the First World Congress in Sports Physical Therapy. These authors identified the need to validate clinical tests for RTS, which include strength (rate of force development, eccentric, and endurance), neuromuscular control (dynamic functional tests and reactive agility tasks), psychological measures, and performance and skill execution.

Several studies have reported that many patients were unable to pass strength, balance, and neuromuscular tests in the time period when many authors allow RTS, typically 6 to 9 months postoperative.[6,16,21,35,43,61,62,81,92,99,103] Boyle et al[16] tested 39 adolescents and 16 adults who underwent transphyseal hamstring ACLR 9 months postoperatively with the functional movement screen and lower quarter Y-Balance tests. An increased risk for lower extremity injury was reported based on an inferior active straight-leg raise score on the functional movement screen. In addition, the adolescents had wider ranges of anterior reach asymmetry compared with the adult group. Toole et al[99] assessed 115 adolescents at a mean 8 months postoperatively with isokinetic testing (180 deg/s), 4 single-leg hop tests, and the IKDC self-reported knee function scale. An LSI ≥90% was required to pass the strength and hop tests, and the IKDC score was required to be ≥90 points. Although all patients had been cleared by their surgeon to RTS, only 13.9% passed all tests. Petersen et al,[74] in a systematic review of 61 articles, concluded that most studies reported muscular imbalances in the ACLR leg, which were most pronounced ≤6 months postoperatively, but could persist up to 2 years and longer.

Reducing the Risk of Reinjury

Studies of adult populations reported decreases in ACLR reinjury rates when objective tests were used before release to full

Table 3. Details of reinjuries

Knee	Variable	Factors	n (%)
ACLR (n = 123)	Cause of reinjury n (%)	High-risk sport (jump/land, pivot, cut)	111 (90)
		Fall, other	5 (4)
		Not provided	7 (6)
	Type of graft n failed (% of total that received the graft)	Bone–patellar tendon–bone autograft (n = 688)	59 (9)
		Hamstring autograft (n = 275)	42 (15)[a]
		Hamstring autograft + Telos ligament (n = 58)	12 (21)
		Tibialis anterior allograft (n = 8)	3 (37)
		Hamstring allograft (n = 32)	2 (6)
		Autograft, graft not provided (n = 178, 1 study)	5 (3)
	Sex n failed (% of sex)	Male (n = 556)	70 (13)[b]
		Female (n = 624)	51 (8)
		Not provided (1 study, 23 male, 36 female)	2
Contralateral ACL (n = 115)	Cause of injury n (%)	High-risk sport (jump/land, pivot, cut)	92 (80)
		Not provided	23 (20)
	Sex n failed (% of sex)	Male (n = 538)	54 (10)
		Female (n = 559)	54 (10)
		Not provided (2 studies, 25 male, 21 female)	7

ACL, anterior cruciate ligament; ACLR, ACL reconstruction.
[a]Compared with bone–patellar tendon–bone autograft odds ratio, 0.52; $P = 0.002$.
[b]Odds ratio, 1.64; $P = 0.01$.

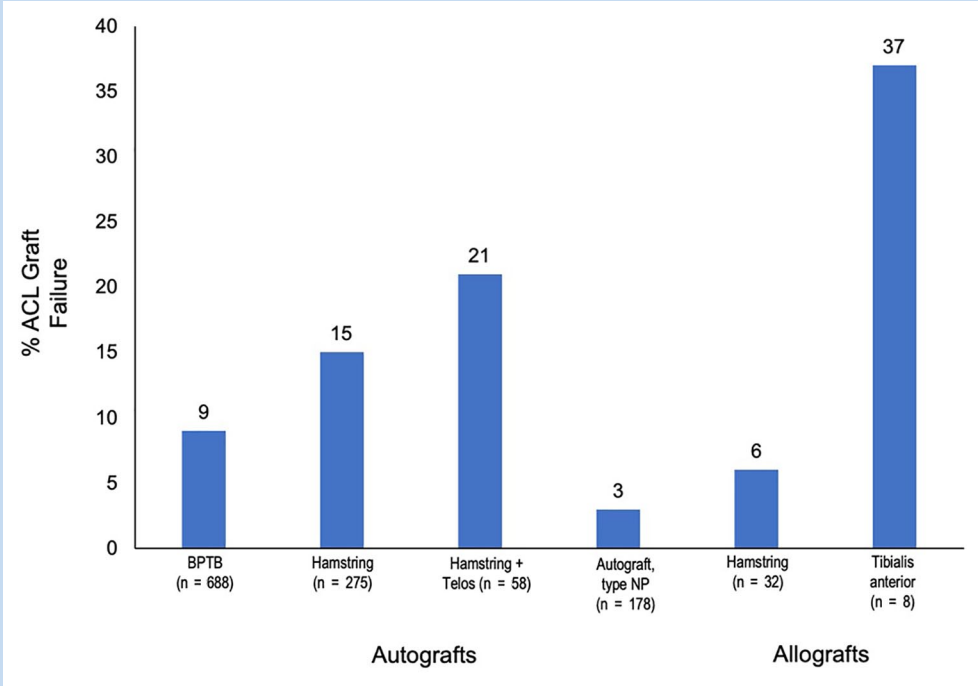

Figure 1. Percentages of anterior cruciate ligament (ACL) reconstruction failure according to the type of graft. BPTB, bone–patellar tendon–bone; NP, not provided.

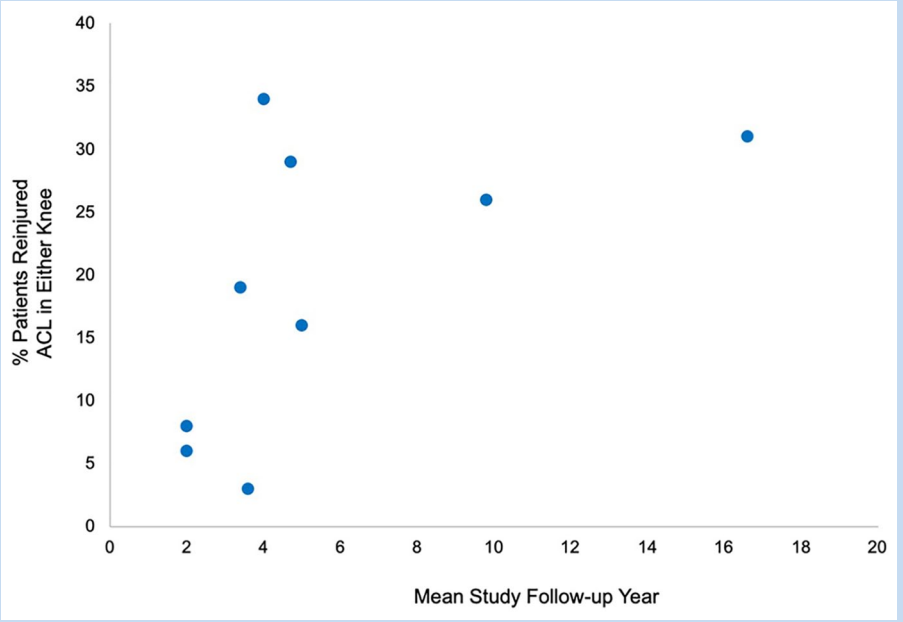

Figure 2. The percentage of patients that suffered tears to the anterior cruciate ligament (ACL) graft, contralateral ACL, and either knee are shown for each study.

competition. Kyritsis et al[51] devised discharge criteria from isokinetic testing, 3 single-leg hop tests, and an agility test in 158 male professional athletes (mean age, 22 ± 5 years). Athletes who did not meet the criteria for all tests and who had a decreased hamstring-to-quadriceps ratio had a 4 times greater risk of ACL graft failure compared with those who met the criteria (33.3% and 10.3%, respectively; hazard ratio, 4.1; $P < 0.001$). Grindem et al[37] reported that patients (mean age, 24.3 ± 7.3 years) who returned to high-risk sports were 4 times more likely to suffer a reinjury (including ACL, meniscal, and cartilage injuries) than those who did not. Their RTS test battery included isokinetic quadriceps testing, 4 single-leg hop tests, and 2 self-reported outcome measures. Patients who passed all test measures had substantial reductions in reinjury rates compared with those who failed (5.6% vs 38.2%, respectively; $P = 0.07$).

Historically, as early as the 1990s, many authors recommended strength testing prior to the initiation of running and RTS.[4,20,57,64,65,67,68,88] In a study of 40 patients who underwent a bone–patellar tendon–bone allograft and iliotibial band extra-articular procedure, ≥85% quadriceps strength, no symptoms, and a period of 10 to 12 months postoperative were required before patients could return to running.[64] In this group, 92% returned to sport and 3% experienced a graft failure. In a study of 53 patients who received a bone–patellar tendon–bone autograft and in whom noteworthy articular cartilage deterioration was present at surgery, return to recreational sports was allowed using similar criteria.[67] The study reported that 79% returned to mostly low-impact sports and 6% experienced a graft failure.

Postoperative Rehabilitation for the Adolescent Athlete

Postoperative rehabilitation programs and progression to RTS in the adolescent athlete may require differences compared with programs used for adult patients to adjust for issues related to this age group, such as physiological and psychological maturity and psychosocial factors. Forrester et al[32] identified 21 pediatric rehabilitation protocols from an internet-based search. Only 24% recommended passing specific tests, and 19% required surgeon approval for RTS. Greenberg et al[36] surveyed members of the Pediatric Research in Sports Medicine Society to identify clinical practice patterns during ACLR rehabilitation for progression to jogging, modified sports activity, and unrestricted RTS. A total of 60 surgeons (response rate, 91%) participated, the majority of whom were board certified and performed >25 ACLRs each year. Variability was found for time allowed for modified sports activities (4-8 months) and RTS (6-12 months). Objective criteria to begin jogging included measurement of quadriceps strength, which was done using manual muscle testing in 70% and isokinetic testing in 22%, the single-leg squat test in 31%, and straight-leg raise test in 20%. There was no consensus for the LSI goal for initiation of modified sports activity, which ranged from >75% to >95%. Of concern was the finding that 32% of surgeons did not require objective testing for RTS. No surgeon used fear or self-efficacy questionnaires in their RTS assessment.

In the future, objective criteria regarding graft maturation using magnetic resonance imaging (MRI) may be of vital importance in the battery of testing for RTS clearance.[77,78]

Table 4. Criteria for release to sports activities

Study	n	Muscle Strength	Hop Test	Time Postoperatively, mo	Subjective Parameters	Failure Rate, %		
						ACLR	Contralateral ACL	Either Knee
Shelbourne et al[86,89]	624	85% quadriceps strength for team competition				9	7	16
Larson et al[53]	30		90% LSI single-leg hop and triple hop	6-8	"restoration of jump landing and pivoting mechanics"	17	17	34
Morgan et al[60]	242			6-9	"according to an objective assessment of whether the rehabilitation goals had been met"	17	20	37
Kocher et al[50]	59			6		3	0	3
Takazawa et al[95]	52			6		21	9	29
Goddard et al[34]	32			12		6	0	6

ACL, anterior cruciate ligament; ACLR, ACL reconstruction; LSI, limb symmetry index.

Ultrashort echo-time MRI techniques offer improved image quality that allow for the assessment of the status of the ACL graft because they show excellent graft/implant contrast and low metal artifact.[80] In animal models, ultrashort echo-time MRI modifications have allowed high-resolution 3-dimensional images that predicted linear stiffness, yield load, maximum load, and failure load after 1 year postoperatively.[11,12,31]

Study Limitations

There are limitations to this review, including low evidence levels in 7 of the 8 studies, potential for unrecognized failures because not all studies conducted clinical examinations, inability to determine whether reinjuries were contact or noncontact, and exclusion of at least 100 studies due to missing data regarding sport or reinjuries. The heterogeneity of the studies prevented conclusions regarding the effect of resuming high-risk sports compared with low-risk activities on reinjury rates. Whether the use of objective testing and discharge criteria before RTS correlated with lower reinjury rates could not be determined.

CONCLUSION

A high rate of athletes <20 years old returned to sport, but 1 in 5 suffered reinjuries to either knee, and the majority of these occurred during high-risk sports activities. Male patients were more likely than their female counterparts to reinjure the ACL graft. Objective criteria for RTS was rarely mentioned or not detailed. The need for testing of knee stability, strength, neuromuscular control, agility, and psychological measures before RTS remains paramount in young athletes.

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