Return to Sport After Pediatric Anterior Cruciate Ligament Reconstruction

CME

A Systematic Review of the Criteria

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Background: Postoperative rehabilitation is an important component of recovery after anterior cruciate ligament (ACL) reconstruction (ACLR), facilitating successful return to sport (RTS) by reducing risk factors for repeat injury.

Purpose: This systematic review aimed to determine the best protocol for RTS after ACLR in children.

Study Design: Systematic review; Level of evidence, 4.

Methods: PubMed, Embase, PEDro, SPORTDiscus, and Web of Science databases were searched from October 3, 2014, to November 3, 2022. The inclusion criteria were the pediatric population (<18 years old) after ACLR with clear RTS criteria and/or mean/median time to RTS. Multiligament knee injuries were excluded from this study. The methodologic quality of the included articles was assessed using the methodological index for non-randomized studies (MINORS). The highest possible score was 24 points for comparative studies (ie, a study comparing 2 protocols or more). Noncomparative studies or studies with a single protocol could score a maximum of 16 points as assessed by the MINORS score.

Results: The search yielded 1816 titles, and 24 were retained based on the inclusion and exclusion criteria. Every study was published between 2015 and 2022. Among the 24 studies included, 13 were retrospective and 11 were prospective. The mean MINORS score for the noncomparative studies was 13 of 16 (n = 23) and 23 of 24 for the comparative study (n = 1). The studies were categorized into unspecified clearance (n = 10), milestone based (n = 13), and combined time and milestone (n = 1). A total of 1978 patients (57% female) were included in the review. The mean age at ACLR was 14.7 years. The most common endpoint used was graft rupture (0% to 35%). In the unspecified group, the quickest RTS was 5.8 months and the longest was 9.6 months. Statistically significant risk factors for ACL reinjury included younger age and earlier RTS. The latter was a significant contributor to graft failure for combined time-based and milestone-based RTS. In the milestone-based group, the most common criteria were ≥90% limb symmetry measured using hamstring strength, quadriceps strength, and/or hop tests. The mean RTS time was 6.8 to 13.5 months.

Conclusion: RTS should be delayed, when possible, especially in the younger population. A combination of quantitative tests and qualitative tests is also recommended. However, optimal RTS criteria have yet to be determined. Future prospective studies should focus on comparing the different times and milestones currently available.

Keywords: ACL reconstruction; rehabilitation; pediatric population; systematic review

Over the past 2 decades, the prevalence of anterior cruciate ligament (ACL) injuries among patients aged 6 to 18 years has increased by approximately 2.3% per year.[3,11] Studies have proven that nonoperative management of ACL injuries is associated with persistent instability and meniscus degeneration.[17,37] Nonetheless, ACL reconstruction (ACLR) has been associated with excellent long-term results,[14] leading to an increase in surgical management. In fact, from 1994 to 2006, the yearly number of ACLRs performed in patients younger than 15 years rose by >900%.[6,46] A similar trend was observed from 2004 to 2014 with a 600% increase.[42]

Young athletes have high expectations regarding their return to play.[1,32] It is well documented that the pediatric population has a higher rate of ACL rerupture compared with the adult population.[31] Therefore, postoperative rehabilitation plays an important role in a safe return to sport (RTS).[25] Adequate rehabilitation facilitates a successful RTS by optimizing function and reducing the presence of risk factors for repeat injury.[20] However, the criteria for RTS published in postoperative ACLR protocols vary significantly.[30] Yellin et al[49] published a systematic review in 2016 on common rehabilitation principles after pediatric

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ACLR. They found that 50% of protocols were time based (n = 7), and the others were milestone based. They reported a trend toward milestone-based rehabilitation in more recent studies. The time from surgery to RTS ranged from 6 months to >12 months. Yellin et al[49] concluded that additional studies should be conducted to prospectively evaluate rehabilitation protocols and RTS criteria for young athletes.

As there is still little to no high-quality evidence to guide RTS rehabilitation after a pediatric ACLR, the aim of this systematic review was to review the evidence on RTS criteria after ACLR in patients under 18 years.

METHODS

A systematic review was performed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[34] The protocol was registered in Prospero (ID CRD42022368628). Two reviewers (J.-P.L. and L.S.) independently carried out a comprehensive search of the PubMed, Embase, PEDro, SPORTDiscus, and Web of Science databases. As previously mentioned, a similar systematic review was published by Yellin et al[49] in 2016. In their systematic review, Yellin et al included articles up to October 3, 2014; therefore, all databases were searched between October 3, 2014, and November 3, 2022.

The following search terms were used: (ACL OR "anterior cruciate ligament") AND (pediatric OR child* OR preadolescent OR juvenile OR "skeletally immature") AND ("return to sport" OR rehab* OR management OR physical therapy OR physical therapy). Each reference section was hand screened to identify additional studies.

Inclusion and Exclusion Criteria

The inclusion criteria were pediatric population (<18 years old) after ACLR, clear RTS criteria with cutoff values, and/or mean/median time to RTS. Patients with and without meniscal injuries were included. Articles were excluded when no specific population was specified, when patients underwent ACL repair surgery, and when patients had previous injuries or surgeries on the contralateral knee or if patients had a multiligament knee injury. Review articles were also excluded from this study, but their references were screened.

Methodologic Quality Assessment

The methodological index for non-randomized studies (MINORS)[40] instrument was used to assess the quality of the included studies. This instrument contains 12 items, with the first 8 specifically designed for noncomparative studies. Each item is graded from 0 to 2 (0 = not reported, 1 = reported but inadequate, and 2 = reported and adequate). Therefore, the maximum score is 16 for noncomparative studies and 24 for comparative studies. Comparative studies were defined as any studies comparing ≥2 RTS criteria. Noncomparative studies were defined as studies on a single RTS protocol. Each study was independently scored by 2 reviewers (J.-P.L. and L.S.). When necessary, discrepancies were resolved by a discussion between both authors or a consensus with a third author (P.M.).

Data Collection and Extraction

Two authors (J.-P.L. and L.S.) screened the titles and abstracts of the included articles independently. Any discrepancy was resolved through discussion and, if necessary, with another member of the research team (P.M.). Then, 2 authors (J.-P.L. and L.S.) independently retrieved data from the included studies. The information was categorized into basic article information (eg, title, authors, and year of publication), patient background information and methods (eg, sample size, sex, age, skeletal maturity, and injured leg), surgical technique (eg, type of graft and approach used), and postoperative outcomes and complications (eg, length of follow-up, RTS definition, RTS criteria, time to RTS, and reinjury rate). Time to RTS was calculated from the time of ACLR to return to play.

Statistical Analysis

The IBM SPSS Statistics 23.0 software was used to analyze the data. This included a descriptive analysis of all variables, including frequencies, percentages, and means. Regression analysis was done for independent variables such as age, sex, and time to RTS. Statistical significance was defined as $P < .05$.

RESULTS

Our search yielded 1816 titles (Figure 1). After removing duplicates, 1283 articles were screened based on titles and abstracts. Of these, 64 articles were then included

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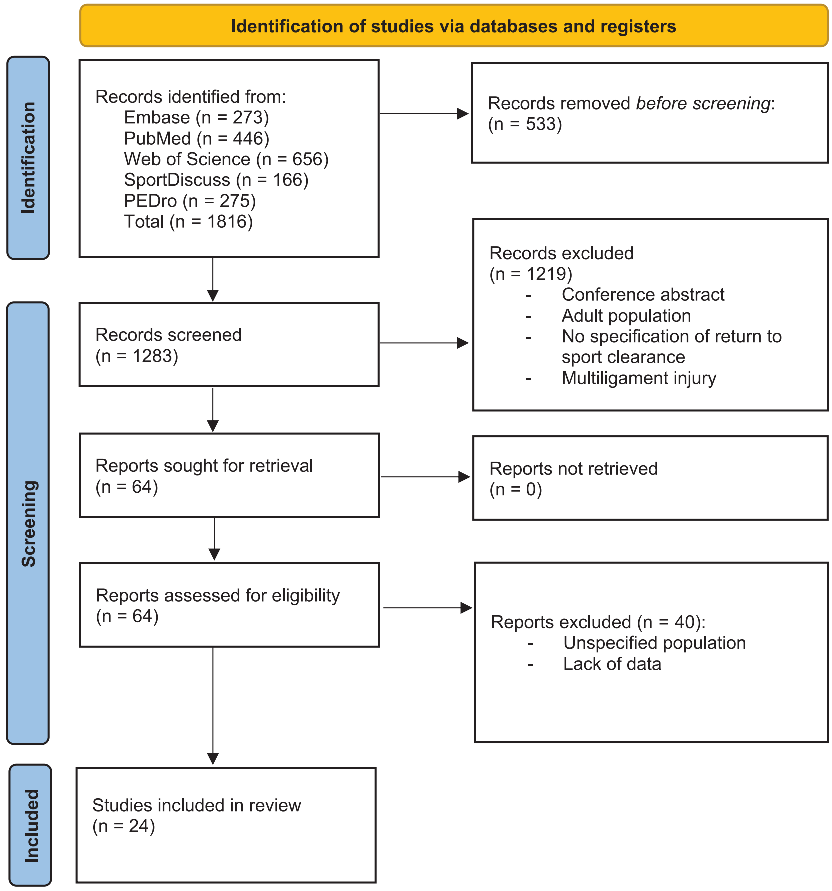

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 flow diagram for new systematic reviews that included searches of databases and registers only.

and screened based on a full-text review. No new articles were found after reviewing the bibliography of each study. A total of 24 articles remained, based on the inclusion and exclusion criteria. Every study was published between 2015 and 2022. A total of 1978 patients (57% female) were included in this systematic review. The mean age at ACLR was 14.7 years. The included studies were categorized into unspecified clearance (n = 10), milestone based (n = 13), and combined time and milestone (n = 1). Any study with a time-based RTS, or a clear time to RTS but no clear RTS criteria was included in the unspecified clearance group. When RTS included physical tests but no cutoffs, the study was labeled as unspecified clearance. Milestone-based studies were defined as any protocol where a specific milestone needed to be met, regardless of the time elapsed. The combination of time and milestone comprised studies including specific times and specific physical ability testing, with defined cutoffs.

Among the 24 included articles,[¶] 13 were retrospective[#] and 11 were prospective (Tables 1-3). The mean MINORS score for the noncomparative studies was 13 of 16 (n = 23). Most points were lost in item 7 (loss to follow-up <5%) and item 8 (prospective calculation of study size). Hansson et al[19] was the only comparative study and obtained a mean MINORS score of 23 of 24 (n = 1). Their study lost 1 point in item 9 (an adequate control group) given the absence of a gold standard.

Table 1 describes the 10 studies[††] included in the unspecified RTS clearance. Chicorelli et al[8] assessed the percentage of skeletally immature patients who returned to sport after ACLR. They found that 96% of patients returned to sport at a median time of 9 months, and of these, 30% returned to a higher level of play; 45%, to the same level; and 22%, to a lower level. Within their sample, 54% had a hamstring autograft; 29%, an iliotibial band autograft; 12%, a patellar tendon; and 5%, an allograft. Kostyun et al[24] compared rehabilitation after hamstring autograft and the difference in RTS in male and female patients. Throughout the rehabilitation process, female patients demonstrated lower self-reported readiness to RTS compared with male patients. However, the difference in RTS between both groups was not significant (8.1 months vs 8.4 months for male and female patients, respec-

[¶]References 2, 4, 7-10, 12, 16, 18, 19, 21, 22, 24, 27-29, 36, 38, 39, 41, 43, 44, 47, 48.

[#]References 2, 4, 7, 8, 10, 19, 28, 36, 38, 41, 44, 47, 48.

[††]References 4, 8, 10, 12, 21, 22, 24, 28, 36, 39.

TABLE 1
Studies Included in This Systematic Review With an Unspecified Return to Sport Clearance

Reference	Year	Type of Study and Level of Evidence	MINORS Score	Study Goal	Participants, n (% Female)	Mean Age, y	RTS Definition	RTS Criteria and Time to RTS	Results
Boyle et al[4]	2016	Retrospective level 4	10/16	Assess through functional movement and dynamic balance if 9 months is adequate for RTS	39 (64)	15.3	Return to participation	RTS at 9.0 months	Adolescent patients undergoing primary ACLR do not consistently recover adequate functional movement patterns by 9 months postoperatively
Chicorelli et al[8]	2016	Retrospective level 4	12/16	Evaluate the percentage of patients with ACLR who RTS	250 (54)	12.7	Classified based on complete return, partial return, and no return	RTS at 9.0 months	At 12 months, 85% of patients had returned to sport; Cox regression did not identify significant predictors of time to RTS
Dekker et al[10]	2017	Retrospective level 4	16/16	Identify risk factors related to RTS that correlate with subsequent ACL injury	85 (60)	13.9	Return to competition	Not specified; RTS mean time of 9.6 months	The reinjury rate = 32%; within this population, an earlier RTS is predictive of a second ACL injury
Domzalski et al[12]	2016	Prospective level 4	14/16	Evaluate the outcomes of transphyseal ACLR	22 (6)	11.7	Return to previous high-level activity	Not specified; return at a mean of 9 months	Over a mean follow-up of 77.2 months; no patient required revision surgery
Ithurburn et al[22]	2019	Prospective level 2b	15/16	Examine differences in knee function and strength at the time of RTS	124 (75)	17.1	Return to preinjury sport participation	Not specified; mean RTS of 8.9 months	There were no differences in terms of knee function and strenght between those who successfully resumed preinjury levels of sport participation and those who sustained a second ACL injury
Ithurburn et al[21]	2022	Prospective level 1	10/16	Derive KOOS functional recovery target values from uninjured young athlete data and correlate with clinical measures at the time of RTS clearance	166 (68)	16.9	Return to preinjury sport participation	Not specified; mean RTS of 8.3 months	Significant predictors for functional recovery were younger age, hamstring graft, pediatric ACLR, quadriceps strength LSI >90%, single-hop LSI >90%, and crossover-hop LSI >90%
Kostyun et al[24]	2021	Prospective level 4	14/16	Determine if readiness to RTS differs between male and female	93 (55)	15.4	Return to preinjury level	Mean RTS of 8.0 months	Male patients had a mean RTS of 8.1 months and female patients of 8.4 months
Law et al[28]	2021	Retrospective level 4	16/16	Examine the effect of age on ACLR rehabilitative outcomes and identify reinjury risk factors	273 (57)	15.7	RTS unspecified	Mean discharge from physical therapy of 5.8 months	Reinjury was recorded in 17.2%; adolescents who are younger, receive surgery and after surgery PT sooner, or attend fewer PT sessions may be at an increased reinjury risk
Placella et al[36]	2016	Retrospective level 4	13/16	Evaluate the RTS outcome of patients after ACLR using the all-inside technique	24 (42)	13.2	RTS unspecified	Isokinetic testing with functional assessment; however, no cutoff provided; mean RTS of 6.4 months	At a minimum 8-year follow-up, the mean leg-length difference was 0.4 cm
Shamrock et al[39]	2022	Prospective level 4	14/16	Evaluate the outcomes of partial-transphyseal over-the-top ACLR	12 (8)	12.8	Return to same or higher level of activity	Mean RTS of 7.4 months	Two cases of graft rupture (16.7%)

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; KOOS, Knee injury and Osteoarthritis Outcome Score; LSI, limb symmetry index; MINORS, methodological index for non-randomized studies; PT, physical therapy; RTS, return to sport.

TABLE 2
Articles Included in This Systematic Review Assessing a Milestone-Based Return to Sport Clearance

Reference	Year	Type of Study and Level of Evidence	MINORS Score	Study Goal	Participants, n (% Female)	Mean Age, y	RTS Definition	RTS Criteria and Time to RTS	Results
Astur et al[2]	2019	Retrospective level 4	12/16	Analyze characteristics of patients with an ACLR and determine potential risk factors for ACL rerupture	52 (44)	13.9	RTS unspecified	Rehabilitation for 6 to 9 months; released once absence of apprehension + LSI assessment; mean RTS time of 7.4 months	18 patients sustained a rerupture.
Calvo et al[7]	2015	Retrospective level 4	14/16	Evaluate the functional outcomes of patients after transphyseal intra-articular ACLR	27 (41)	13.0	Returning to contact sport	≥90% LSI; mean RTS not reported	Three patients tore their graft at 7, 35, and 99 months postoperatively
Cordasco et al[9]	2017	Prospective level 4	10/16	Evaluate the 2-year clinical outcomes of all-inside, all-epiphyseal ACL reconstruction in skeletally immature athletes	23 (26)	12.3	Return to unrestricted sport	LSI, alignment control, and ability to decelerate during progressively challenging movements; mean RTS at 13.5 months	Second surgery was required in 2 of the 23 athletes, with only 1 ACL revision
Ekås et al[16]	2019	Prospective level 4	14/16	Evaluate the outcomes of patients with ACL deficiency treated with active rehabilitation vs delayed ACLR	24 (34)	15.3	Return to preinjury activity level	Perform all 4 single-leg hop tests and 90% LSI; time to RTS not reported	One patient had graft rupture <10 months after ACLR
Graziano et al[18]	2017	Prospective level 4	11/16	Determine the effectiveness of a criteria-based rehabilitation progression and RTS criteria	42 (29)	12.0	Return to unrestricted sport	Dartfish motion analysis, KT-1000 arthrometry, isokinetic strength testing, and single-leg hop test; mean RTS at 12 months	A second injury was sustained by 5 of the 30 male patients (4 ACL injuries and one medial meniscus injury) (16.7%) and 2 of the 12 female patients (all ACL injuries) (16.7%)
Larson et al[27]	2016	Prospective level 4	12/16	Evaluate outcomes of transphyseal allograft ACLR in skeletally immature patients	30 (55)	13.9	Return to previous level of sport	Functional testing including 90% single-leg hop, triple hop; mean RTS time not reported	16.7% of patients sustained a rerupture and another 16.7% a contralateral ACL tear
Losciale et al[29]	2022	Prospective level 2	11/16	Assess if specific RTS criteria coincide with restoration of lower limb movement mechanics during a bilateral landing task	39 (56)	15.4	Return to preinjury sport participation	≥90% limb symmetry; mean RTS of 7.4 months	Young athletes who pass RTS criteria after ACLR land symmetrically during a double-leg task, but symmetry was achieved by reducing loading on both limbs
Roman et al[38]	2021	Retrospective level 4	12/16	Determine if knee strength differences exist according to age (group A = early adolescent and group B = late) and sex during ACLR rehabilitation	144 (57)	15.3	RTS unspecified	≥90% limb symmetry; mean time of 7.5 months	For quadriceps LSI, 47% in group A met the 90% threshold, and 51% in group B met the 90% LSI threshold; similar trends were observed for hamstring peak torque

(continued)

TABLE 2
(continued)

Reference	Year	Type of Study and Level of Evidence	MINORS Score	Study Goal	Participants, n (% Female)	Mean Age, y	RTS Definition	RTS Criteria and Time to RTS	Results
Sugimoto et al[41]	2020	Retrospective level 4	12/16	Assess the proportion of skeletally immature patients needing ACLR who achieve ≥90% LSI at 6 to 9 months	105 (41)	13.4	RTS unspecified	≥90% limb symmetry; mean testing at 6.8 months	4.2% of skeletally immature patients needing ACLR demonstrated 90% lower extremity recovery at 6.8 months after ACLR
Toole et al[43]	2017	Prospective level 2	13/16	At RTS, the IKDC, quadriceps and hamstring strength, and single-leg hop LSI were assessed	115 (77)	17.1	Return to unrestricted sport	≥90% limb symmetry; IKDC of >90; mean testing at 8.2 months	13.9% met the 3 criteria; 23 sustained a second ACL injury in the year after RTS clearance
Wall et al[44]	2017	Retrospective level 4	13/16	Evaluate the outcomes of patient after all-epiphyseal ACLR	27 (15)	11.0	Return to unrestricted sport	Between 6 and 9 months postoperatively, with ≥85% to 90% LSI	Mean follow-up of 3.8 years; RTS rate was 81%; retear rate was 11%
Willson et al[47]	2018	Prospective level 4	13/16	Evaluate the outcome of a hybrid physeal-sparing ACLR technique	23 (26)	13.0	RTS unspecified	Mean clearance at 8 months with ≥90% LSI, hop tests, and Pedi-IKDC questionnaire	At a mean of 19 months, the mean Pedi-IKDC score was 96
Wren et al[48]	2018	Retrospective level 4	10/16	Assess biomechanics and LSI after ACLR during a single-leg hop for distance	46 (59)	15.6	Return to unrestricted sport	Not specified; symmetry was defined as LSI ≥90%; mean testing at 7.2 months	Both patients with symmetry and patients with asymmetry offloaded the operative knee; hop distance symmetry may not be an adequate test of RTS readiness

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee; LSI, limb symmetry index; MINORS, methodological index for non-randomized studies; Pedi-IKDC, Pediatric IKDC; RTS, return to sport.

TABLE 3
Article Included in This Systematic Review Assessing a Combination of Time- and Criteria-Based Return to Sport Clearance

Reference	Year	Type of Study and Level of Evidence	MINORS Score	Study Goal	Participants, n (% Female)	Mean Age, y	RTS Definition	RTS Criteria and Time to RTS	Results
Hansson et al[19]	2022	Retrospective level 4	23/24	Describe the long-term reinjury risk after 2 different postoperative rehabilitation programs	193 (61)	13.2	RTS unspecified	>9 months (group A) and >6 months (group B) after surgery + single-leg hop for distance, which should reach 90% LSI (for both groups)	8% of the patients in group A and 19% of the patients in group B underwent ACL revision.

ACL, anterior cruciate ligament; LSI, limb symmetry index; MINORS, methodological index for non-randomized studies; RTS, return to sport.

tively). The study by Law et al[28] had the shortest mean RTS time with 5.8 months before discharge from physical therapy. This study aimed to examine the effect of age on ACLR rehabilitation, although it did not comment on skeletal maturity. With a median follow-up time of 3.1 years, they found a reinjury rate of 17.2%. The median time to reinjury was 13.4 months after ACLR. They concluded that potential risk factors for reinjury were younger age (hazard ratio [HR], 1.264 per year decrease in age), attending fewer post-ACLR physical therapy sessions (HR, 1.118

per decrease of 3 sessions/visits), and starting physical therapy within 3 days after ACLR (HR, 3.068). In their study population, 66% had a hamstring autograft; 17%, a patellar tendon autograft; 4%, a quadriceps autograft; another 4%, iliotibial band autografts; and 5%, an allograft. Meanwhile, the longest RTS time was reported by Dekker et al,[10] with 9.6 months. Their study also assessed the risk factors of RTS correlated with subsequent ACL injury. No patients were cleared before 6 months. They found a reinjury rate of 32% with a minimum follow-up of 2 years. Their results showed that time to RTS was a significant risk factor, where a longer RTS time was protective against an ipsilateral or contralateral reinjury (HR, 0.87 per month, for each 1-month increase). Their study population consisted of 77% skeletally immature patients. Graft types included 73% hamstring autografts, 15% patellar tendon autografts, and 10% hamstring autografts with allograft augment.

Other studies in the unspecified category correlated specific time of RTS with the Knee injury and Osteoarthritis Outcome Score (KOOS), strength limb symmetry index (LSI), and hop test. Ithurburn et al[21] calculated KOOS functional recovery target scores and correlated the scores with the clinical measures at the time of RTS. They found that at 8.3 months, a better KOOS was associated with younger age and having >90% LSI for quadriceps strength and single-leg hop tests. In terms of graft type, 56% of patients had hamstring autografts, 37% had patellar tendon autografts, and 7% had allografts. Unfortunately, their study did not comment on skeletal maturity. The other study by Ithurburn et al[22] retrospectively compared knee function and strength at the time of RTS between the group of patients who returned to their preinjury level, the group that did not return to their preinjury level, and the group that sustained a second ACL tear. They reported a 21% reinjury rate, with an RTS at 8.9 months and a 1-year follow-up.[22] The participants that sustained an ACL graft injury were significantly younger than those who sucessfully resumed sports (P = .024). However, a greater absolute single-leg triple hop performance (P > .05) and a similar KOOS, quadriceps LSI, hamstring LSI, and single-hop test was found in the reinjured group compared with those who resumed physical activity.[22] Again, skeletal maturity was not addressed. Regarding graft type, 51% had a hamstring autograft, 43% had patellar tendon autografts, and 6% had an allograft. At 9 months after ACLR, Boyle et al[4] studied the Functional Movement Screen to assess movement competency and the Lower Quarter Y-Balance Test to assess single-limb dynamic balance. They compared the skeletally mature group (closed distal femoral growth plate) with the skeletally immature group (open distal femoral growth plate). They found that the skeletally immature group had a lower straight-leg raise score compared with the skeletally mature group. Similar outcomes were noted for the deep squat, inline lunge, rotatory stability, hurdle step, shoulder mobility, and trunk stability pushup scores. Asymmetry in ≥1 test was noted in 35% of skeletally immature patients and 55% of skeletally mature patients. No differences were noted in the Lower Quarter Y-Balance Test and KT-1000 arthrometer tests. Within their sample, all patients received a hamstring graft, and 44% of patients were skeletally immature.

Domzalski et al[12] and Shamrock et al[39] evaluated transphyseal ACLR outcomes with hamstring autograft in skeletally immature patients. Domzalski et al found increasing International Knee Documentation Committee (IKDC) and Lysholm scores postoperatively, and 86% of patients returned to their preinjury sport level in 9 months, without revision surgery over a 77.2-month follow-up. Shamrock et al found a mean RTS of 7.4 months with a 16.7% graft rupture rate. Placella et al[36] assessed long-term outcomes of ACLR with manual drilling in skeletally immature professional athletes with a minimum 8-year follow-up. They found no rerupture with a mean RTS time of 6.4 months and 11% reduction in flexion strength and 6% reduction in extension strength compared with the contralateral leg on isokinetic evaluation.

Table 2 describes the 13 studies[‡‡] that assessed a milestone-based RTS clearance. Astur et al[2] specifically aimed to identify potential risk factors for graft rupture in skeletally immature patients after ACLR with hamstring autograft. Both groups had a similar time to return to activity (7.4 months). The total sample size was 52 patients, and 35% sustained a graft rerupture. After data analysis, they found that patients who sustained a rerupture had lower Tegner and Lysholm scores upon RTS. Nonetheless, among the other included studies, the most common criteria were ≥90% LSI measured using hamstring strength, quadriceps strength, or hop tests. Sugimoto et al[41] aimed to determine the proportion of skeletally immature patients with ACLR who achieved ≥90% LSI between 6 and 9 months postoperatively. They found that, at 6.8 months, only 4.2% of patients met the 90% LSI threshold. Within their study population, 51% had a hamstring autograft, and 49% had an iliotibial band autograft. Roman et al[38] conducted a study on the relationship between knee strength, age group, and sex among adolescents in the later stage of ACLR rehabilitation. The study was carried out 7.5 months after ACLR, before patients were cleared for RTS. The authors found that age had a statistically significant effect on combined knee strength outcomes (P = .001). However, there were no differences in quadriceps and hamstring peak torque between age groups after body mass normalization (P = .16-.49). A significant effect based on sex was also observed (P < .001). The researchers noted that 47% and 51% of patients met the quadriceps peak torque LSI in the early and middle adolescent age groups, respectively, and 44% and 53% met the hamstring peak torque LSI in the same age groups. All included patients had hamstring autografts, and 92% were skeletally mature.

Toole et al[43] used tests such as the IKDC, LSI for quadriceps and hamstring strength, and single-leg hop test LSI at the time of RTS to correlate with sport participation level at 1 year after RTS. Criteria for RTS included IKDC score >90, ≥90% LSI for quadriceps and hamstring strength, and single-leg hop test LSI. Only 13.9% of participants met all 3 criteria during RTS testing that took place

‡‡References 2, 7, 9, 16, 18, 27, 29, 38, 41, 43, 44, 47, 48

at a mean of 8.2 months. They found a 20% reinjury rate at 1-year post-RTS clearance. A higher proportion of athletes who met both quadriceps and hamstring LSI cutoffs maintained or improved their sport participation level at 1 year. No difference was found for the group that returned to their preinjury level when comparison was based on the number of criteria met. The study included 50% hamstring autografts, 43% patellar tendon autografts, and 7% allografts. Skeletal maturity was not discussed. Losciale et al[29] aimed to correlate clearance for RTS with restoration of biomechanics in bilateral landing. Even though 39 patients met the criteria, they had lower uninvolved limb values when compared with the group that had a failed test. This suggests that symmetry was achieved by reducing the load on both limbs. Again, their study did not comment on the patients' skeletal maturity and consisted of 90% hamstring autografts and 10% patellar tendon autografts. Wren et al[48] reached a similar conclusion while assessing the biomechanics and symmetry of patients who underwent ACLR during a single-leg hop test. They found that both patients with symmetry and those with asymmetry offloaded the operative knee. They suggested that hop distance symmetry was not an adequate test for RTS readiness. There was no description of skeletal maturity or the graft type used in their sample.

Graziano et al[18] recruited 42 skeletally immature patients who underwent ACLR to assess the effectiveness of a criteria-based rehabilitation program based on the efficiency of return to activity and prevention of reinjury. All patients had a hamstring autograft. RTS clearance was based on isokinetic LSI, single-leg hop test, and the KT-1000 arthrometry, which examined side-to-side differences for anterior tibial translation and compliance. Dartfish motion analysis was also used for testing sport-specific exercises. The movement patterns progressed by level and were based on the specific sport. The mean time for RTS was 12.0 months. An ACL graft injury rate of 10% was found. Nineteen patients returned before 12 months, of whom 4 sustained a second ACL injury (21%). Three patients who returned to sport against medical advice sustained another ACL injury. A similar analysis was also done by Cordasco et al,[9] who evaluated the clinical outcome of the all-epiphyseal ACLR surgery. At 2 years postoperatively, they assessed symmetry, alignment, strength, neuromuscular control, and the ability to decelerate during sport-specific exercises of gradual intensity. Their mean time to RTS was 13.5 months. Only 1 ACL revision over 23 cases was reported at a mean of 2 years after ACLR. Again, all their patients were skeletally immature and had a hamstring autograft.

In studies conducted by Calvo et al[7] and Larson et al,[27] the transphyseal ACLR technique with hamstring graft was evaluated in skeletally immature patients. Both studies reported a high rate of successful RTS, although there was no record of the time to RTS. However, 3 patients experienced graft ruptures at different time points after reconstruction (7, 35, and 99 months).[7] Another study by Wall et al[44] evaluated the outcomes of all-epiphyseal ACLR with hamstring autografts in skeletally immature patients. Their RTS criteria was ≥85% to 90% LSI in addition to hop and agility tests. Although they did not mention the mean RTS time, a mean RTS rate of 81% and a graft rupture rate of 11% were noted. Reinjury was more common in patients with associated injuries and in those who played higher-level sports. The reported mean IKDC/Pediatric IKDC score was comparable with that reported with the transphyseal technique (96.5 vs 94, respectively). The hybrid physeal-sparing ACLR method was also evaluated by Willson et al.[47] Their study population consisted of skeletally immature patients after hamstring autograft. They reported that 8.7% of patients had a leg-length discrepancy 6 years after ACLR. Their mean RTS time was 8 months, without specifying the rerupture rate.

Furthermore, Ekås et al[16] compared the nonoperative management of ACL tear with delayed ACLR. Up to 50% of patients were doing well with nonoperative management after ACL tear. Among the other 50% with an ACLR, the criteria for RTS were single-leg hop tests and 90% LSI. Despite this, 1 patient had an ACL tear <10 months after ACLR. Their patient population consisted of skeletally immature patients, in whom 88% received a hamstring autograft; 8%, a patellar tendon autograft; and 4%, a quadriceps autograft.

Table 3 describes the only study that compared 2 groups with a combination of time and criteria in their RTS algorithm. Hansson et al[19] aimed to evaluate the long-term outcome of 2 different postoperative rehabilitation programs after pediatric ACLR. These 2 groups included patients >9 months after ACLR in addition to single-leg hop for distance, which should reach 90% LSI (group A; n = 116), and patients >6 months after surgery in addition to single-leg hop for distance, which should reach 90% LSI (group B; n = 77). An overall revision rate of 12% was found with an additional 12% who sustained a contralateral ACL injury. Of the second injuries, 33% and 40% occurred during the first 12 months in groups A and B, respectively. The RTS protocol was the only significant variable (P = .019). In fact, only 8% of patients in group A, compared with 19% in group B, sustained a reinjury. Within their sample, 89% were skeletally immature, 5% were skeletally mature, and their team did not have the information for 6% of patients. All patients had a hamstring autograft.

In this review, 13 articles described their rate of reinjury.[§§] Analysis of those studies showed that mean follow-up ranged from 1.5 to 10.6 years after ACLR. When all 13 studies are combined, 225 of 1028 patients sustained an ACL injury after ACLR (ipsilateral or contralateral). This represents an injury rate of 22%, which includes a graft tear rate of 15%. The relative rate for graft rupture ranged from 0% to 35%. The comparison of graft rupture rates between the unspecified group and the milestone-based group did not reach statistical significance (P = .42). However, 2 independent variables were described as statistically significant predictive factors of graft rerupture. Three studies, Dekker et al,[10] Law et al,[28] and

§§References 2, 7, 10, 16, 18, 19, 22, 27, 28, 36, 39, 43, 44.

Hansson et al,[19] concluded that earlier RTS was a predictive factor for reinjury. The other significant variable, younger age, was reported by Law et al[28] and Ithurburn et al.[22] Given the lack of information to separate and compare the group without reinjury from the group with reinjury, it was not possible to confirm these correlations in our statistical analysis. However, a regression analysis did not find a linear correlation between independent variables and rerupture rates within the reinjury group. The independent variables used were age, sex, and time to RTS. Nevertheless, none of the variables reached statistical significance ($P > .05$).

DISCUSSION

Young athletes are often eager to RTS after ACLR. This was demonstrated in a meta-analysis that showed a 92% RTS and 81% return to competitive sports.[23] However, the rate of rerupture is a serious concern, with rates as high as 20% reported.[45] In our study, the mean time before RTS ranged from 5.8 to 13.5 months. Described significant variables for increased risk of ACLR reinjury included younger age and earlier RTS.

In our systematic review, a few studies reported that earlier RTS was associated with increased risk of reinjury.[10,18,27] However, no linear correlation was found, suggesting there might be an optimal time for RTS that considerably decreases the risk of reinjury. This puts forward the possibility that biological factors play a role in reinjury and healing during childhood. Current tests may not accurately reflect complete healing. Some studies have reported that full recovery from an ACLR may only occur at 2 years after surgery.[15,33] This is partly due to bone bruises, ligamentization, and neuromuscular control not yet back to baseline (or not significantly different) before 2 years after surgery.[33] One of the main drawbacks in delayed RTS is returning to a preinjury level of sport. Children and adolescent athletes develop quickly, and the physical requirements for these high-level athletes increase rapidly as well. This may have serious repercussions on the career of these young patients who may not be able to attain the expected level after 2 years off sport.

Previous studies showed that adolescents were at higher risk of graft rupture compared with adults.[26,35] Similarly, 2 included studies showed that, within the pediatric population, younger age was associated with an increased risk of rerupture.[22,28] Again, our analysis did not show a linear correlation between age and the rerupture rate, suggesting that protocols and RTS should be tailored to the different age groups, without the need for a gradual increase. Nonetheless, other parameters such as body mass or bone age might blur the statistical analysis and play a role in reinjury/healing as suggested by Roman et al.[38]

Among other considerations, skeletal maturity is important and should be factored in the choice of rehabilitation protocol for these patients. As described above, not all studies were homogeneous regarding physeal status. Although considered minors, some patients aged <18 years can have the physiologic characteristics of adults. This may have a considerable effect on rehabilitation and subsequent RTS, suggesting maturity-specific rehabilitation strategies.[4]

Younger patients are believed to put more stress on the reconstructed grafts.[13] Therefore, the surgical technique used and graft characteristics also have an effect on RTS. Not all techniques have the same effect on patients, which may lead to differences in healing and postoperative course. For example, a patellar tendon autograft was shown to heal faster but is contraindicated in skeletally immature patients.[5] Again, this demonstrates that skeletal maturity may influence healing but also that surgical technique may influence rehabilitation. The included studies did not provide the details required to compare surgical technique, RTS time, and failure rate. However, it is possible that these factors act as confounders in the RTS analysis.

This systematic review has some limitations. When no specific objective criteria are set, the RTS criteria are subject to interrater variability, which decreases the methodologic quality of the study. As reported by Law et al,[28] correlating the number of postoperative physical therapy visits with the risk of ACL reinjury can introduce a confounding bias in the analysis. In fact, insurance approval varies widely, which may limit the accessibility of physical therapy to those with a lower socioeconomic status. After patients reach 18 years old, they are no longer eligible for most pediatric orthopaedic clinics. Therefore, some reinjuries may be missed, which significantly decreases the evidence of this systematic review. Finally, although we attempted to provide a definition of RTS for each study, it was not always defined, and there were inherent differences between the definitions reported. The injury risk for an athlete returning to simple practice versus another returning to competition or unrestricted activity will be different. This may affect the reinjury risk and the results of this study. The results and comparisons reported in this study need to be interpreted with caution.

CONCLUSION

RTS clearance is an important step in an athlete's rehabilitation process, and specific guidelines should be implemented to prevent graft rupture. Multiple time and milestone criteria were assessed with varying levels of success. Independent variables identified for graft failures in the RTS phase were younger age and earlier RTS. Therefore, RTS should be delayed, when possible, especially in the younger population. However, optimal RTS criteria have yet to be determined. Future prospective studies should focus on comparing the different times and milestones currently available.

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