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Over 90 % of children and adolescents return to sport after anterior cruciate ligament reconstruction: a systematic review and meta-analysis

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Abstract

Purpose To evaluate the rate at which children and adolescent athletes return to sporting activities after anterior cruciate ligament (ACL) reconstruction.

Methods Three databases, PubMed, MEDLINE, and EMBASE, were searched from database inception until September 9, 2017 by two reviewers independently and in duplicate. The inclusion criteria were English language studies that reported return to sport outcomes. Book chapters, conference papers, review articles, and technical reports were excluded. The rate of return to sports was combined in a meta-analysis of proportions using a random-effects model.

Results Overall, 20 studies with a combined total of 1156 ACL reconstructions met the inclusion criteria, with a mean age of 14.3 years (range 6–19) and a mean follow-up time of 6.5 years (range 1–22). All studies were level IV evidence (14 retrospective case series and 6 prospective case series). The pooled rate of return to any sport participation was 92.0% [95% confidence interval (CI), 86–96%]. The pooled rate of return to pre-injury level of sport was 78.6% (95% CI 71–86%) and that to competitive level of sport was 81.0% (95% CI 62–94%). A total of 93 of the 717 assessed athletes (13%) sustained re-injuries with graft ruptures, and in 91 of 652 patients (14%), contralateral ACL injuries were reported on final follow-up.

Conclusion Pooled results suggest a high rate of return to sport following ACL reconstruction in children and adolescent athletes; however, this is associated with a relatively high rate of graft rupture and a similar rate of contralateral ACL injury. This study provides clinicians with evidence-based data on the ability of children and adolescent athletes to return to sport after ACL reconstruction, an important consideration for athletes of this population with ACL injuries.

Level of evidence IV, systematic review of level IV studies.

Keywords Pediatric · Adolescent · Child · Anterior cruciate ligament reconstruction · Sport

Introduction

More than 120,000 anterior cruciate ligament (ACL) reconstructions are performed per year in the US [27]. In the pediatric population, the rate of ACL reconstruction has been steadily increasing over the past 20 years [12], owing in part to the increased sport participation by younger athletes [13]. It has been estimated that 50.9 [95% confidence interval (CI) 48.8–53.0] per 100,000 children aged 10–19 undergo ACL reconstruction per year [12].

Historically, non-operative or delayed treatment of pediatric ACL injuries has been preferred over surgical reconstruction to avoid iatrogenic growth plate disturbances, and to allow for increased psychological maturity for compliance with postoperative rehabilitation [1]. However, delayed reconstruction has been shown to increase the risk

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of secondary meniscal and chondral injuries in the pediatric population [1]. Recent literature has also favored early ACL reconstruction over delayed or non-operative management in children and adolescents, reporting improved stability and activity levels in those who had undergone early surgery [34]. Moreover, delayed reconstruction may increase the risk of secondary meniscal and chondral injuries in the pediatric population [1]. Furthermore, delaying surgery results in significantly reduced rates of participation in higher level sport [30], and this must be carefully considered in the management of these patients as sport restriction is not feasible in this age group [33].

While the rate of return to sport has been synthesized in systematic reviews and meta-analyses for all individuals undergoing ACL reconstruction 2], the rate at which pediatric patients return to sports is unclear. This is vital information to pediatric athletes, wherein one of the most important outcomes for these patients is the ability to return to sport. The purpose of this systematic review and meta-analysis is to examine the rate at which children and adolescent athletes return to sport after ACL reconstruction.

Materials and methods

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement was used for the reporting of study selection [29].

Search strategy

The online databases PubMed, EMBASE, and MEDLINE were searched for literature addressing return to sports following ACL reconstruction in the pediatric population from database inception until September 9th, 2017. The search terms "ACL", "Adolescent/pediatric", and "sport" were used (Table 6 in "Appendix").

Study screening

Two reviewers (JK and MM) independently screened the titles, abstracts, and full-text articles resulting from the searches. Any disagreements were resolved by consensus discussion between reviewers and a senior author (ORA) when necessary. The references of the included studies were then screened for additional articles that may not have been captured by the initial search strategy.

Assessment of study eligibility

The research question and eligibility criteria were determined a priori. The inclusion criteria included studies written in English, human studies, and studies investigating return to sport following ACL reconstruction in children or adolescents. The age range of children/adolescents was defined as those age 19 and younger. Studies of all levels were included. Cadaveric studies, animal studies, conference papers, book chapters, review articles, and technical reports were excluded.

Quality assessment

The Methodological Index For Non-Randomized Studies (MINORS), which was designed to assess the methodological quality of comparative and non-comparative, non-randomized surgical studies, was applied to the included studies and was scored independently by two reviewers (JK and MM) [37]. The MINORS checklist assigns a maximum score of 16 for non-comparative studies and a maximum score of 24 for comparative studies. Any disagreements were resolved by consensus discussion between reviewers and a senior author (ORA) when necessary.

Assessment of agreement

Inter-reviewer agreement was assessed by the kappa (κ) statistic for the title, abstract, and full-text screening stages. An intra-class correlation coefficient (ICC) was calculated for the quality assessment using the MINORS criteria. Agreement was categorized a priori as follows: κ/ICC of 0.61 or greater was considered substantial agreement; κ/ICC of 0.21–0.60, moderate agreement; and κ/ICC of 0.20 or less, slight agreement [25].

Data abstraction and statistical analysis

Two reviewers (JK and MM) collected data in duplicate and recorded them in a Microsoft Excel spreadsheet (Version 2007, Microsoft, Redmond, WA, USA). Data regarding authors, year of publication, location of study, study design, level of evidence [42], sample size, age, gender, follow-up, rehabilitation protocols, graft rupture rates and contralateral ACL injury rates, and complications were recorded.

The primary outcome was the rate at which patients returned to sport. A meta-analysis of proportions was conducted to determine the pooled rate of return to sport, and return to pre-injury level of sport. Subgroup analyses were conducted where possible. To establish the variance of the raw proportions, a Freeman–Tukey transformation was applied [15]. The transformed proportions were then combined using the DerSimonian–Laird random-effects model (to incorporate the anticipated heterogeneity) [11]. The proportions were back-transformed using an equation derived by Miller [23]. The Chochran Q and I^2 tests were used to assess heterogeneity. Values of I^2 between 25 and 49% were

considered "low", 50–74% "moderate", and values greater than 75% considered to be high statistical heterogeneity [20].

For other variables, where results were presented in a non-uniform nature across studies, the results are presented in narrative summary fashion. Descriptive statistics including means, proportions, ranges, kappa values, and ICC values were calculated using Minitab® statistical software (Version 17, Minitab Inc., State College, USA).

Results

Search strategy and study characteristics

The initial search of three databases resulted in 3578 total studies. A systematic screening approach removed articles failing to meet inclusion criteria and resulted in 20 available full-text articles for review (Fig. 1). There was substantial agreement among reviewers at the title ($\kappa = 0.842$; 95% CI 0.819–0.865), abstract ($\kappa = 0.871$; 95% CI 0.831–0.911), and full-text ($\kappa = 1.00$) screening stages. A total of 20 studies, including 1156 pediatric patients, met the inclusion criteria and were included for assessment, 45% (490 of 1088 reported) of which were female. The mean age of patients included was 14.3 years (range 6–19 years), and the mean follow-up time was 6.5 years (range 1–22 years).

Study quality

Fourteen retrospective case series and six prospective case series were identified. The median MINORS scores for these non-comparative studies were 9 out of 16 (range 6–11). Overall, 100% of studies had a clearly stated aim, 75% had appropriate endpoints, 90% had an appropriate follow-up period, and 80% had loss of follow-up less than 5%. However, only 30% of studies had prospective collection of data and only 10% of studies had unbiased assessment of study endpoints. There was substantial inter-rater agreement for the MINORS score with an ICC of 0.836 (95% CI 0.782–0.890) (Table 1).

Patient characteristics

The physeal status was reported in 370 patients, of which 346 had an open physis on pre-operative radiographic assessment. Tanner stages were reported in 190 of the patients of which 85 (45%) were Tanner stages 1 or 2, 53 (28%) were Tanner stage 3, 51 (27%) were Tanner stage IV, and 1 (< 1%) was Tanner stage V. In the studies where

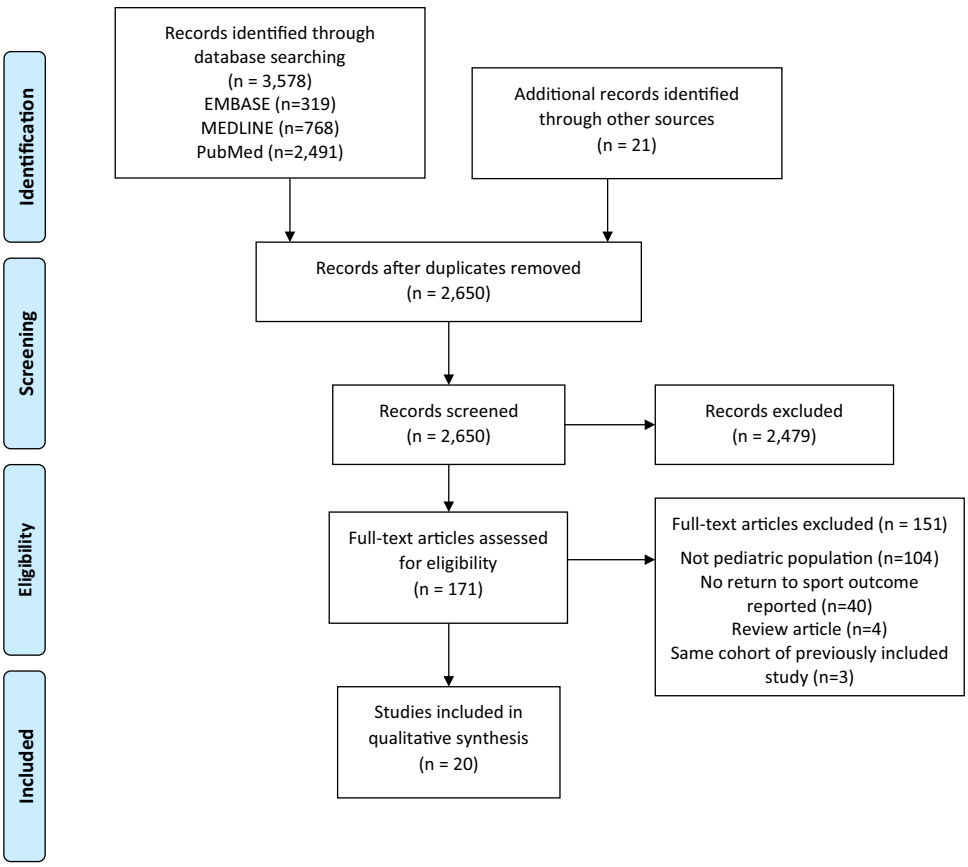

Fig. 1 PRISMA flow diagram of the search strategy for articles assessing return to sport after pediatric ACL reconstruction

Table 1 Study characteristics

References	Study design (level of evidence)	Minors score	Number of patients	% female	Follow-up time (range), months	Mean age (range), years
Calvo et al. [3]	Retrospective case series (IV)	9	27	41	10.6 years (range 10–13 years)	13 years (range 12–16 years)
Cohen at al. [5]	Retrospective case series (IV)	9	26	58	45 ± 18.3 months	13.3 years (11–15)
Cordasco et al. [6]	Prospective case series (IV)	10	23	26	32.1 months (range 24–45 months)	12.2 years (range 9.9–14.5 years)
Chicorelli at el. [4]	Retrospective case series (IV)	7	250	54	24 months	12.7 years (range 6–14)
Dekker et al. [9]	Retrospective case series (IV)	11	85	60	48.3 ± 15.3 months	13.9 ± 2.1 years (range 6 to 17 years)
Demange et al. [10]	Prospective case series (IV)	10	12	42	15-years (range 15–22 years)	10.7 years (range 8.3–12.4 years)
Giudici et al. [8]	Prospective case series (IV)	9	19	26	5 years	13.9 years (12 to 16)
Goddard et al. [17]	Prospective case series (IV)	10	29	38	2 years	13 years (range 8–16 years)
Graziano et al. [18]	Prospective case series (IV)	9	42	29	NR	12 years (range 10–15 years)
Holwein et al. [21]	Retrospective case series (IV)	6	42	33	24.9 months (range 9.3–50.1, SD ± 11.4)	13.2 years (range 9.8–15.9)
Hui et al. [22]	Retrospective case series (IV)	8	16	25	25 months (range 21–34 months)	12 years (range 8–14 years)
Jong et al. [24]	Retrospective case series (IV)	7	11	0	77.7 months (range 45.0–131)	14.7 year (range 13.1–15.5)
Larson et al. [26]	Retrospective case series (IV)	9	29	55	4 years (range 24–84 months)	13.9 years (range 9–16 years)
McCullough et al. [28]	Retrospective case series (IV)	9	68	NR	NR	Range 13–17
Morgan et al. [31]	Prospective case series (IV)	10	242	43	16.5 years	16 years (range 13–18 years)
Placella et al. [33]	Retrospective case series (IV)	7	29	34	8 years minimum	13.15 years (range 9–14 years)
Schmale et al. [35]	Retrospective case series (IV)	7	29	79	4 years (range 2–8 years)	14 years (range and maximum NR), only adolescent and preadolescent patients included
Shelbourne et al. [36]	Retrospective case series (IV)	9	16	31	3.4 ± 1.1 years	14.8 ± 0.68 (range 13.09–15.82 years)
Wall et al. [39]	Retrospective case series (IV)	7	21	19	3.6 ± 1.4 years (range 2.0–6.6 years)	11 years (range 8–15 years)
Webster et al. [41]	Retrospective case series (IV)	8	140	41	5 years (range 3–7 years)	17.2 years (SD, 1.3 years), all patients < 20 years

NR not reported

the pre-operative sports were reported, the most commonly reported sports were football/rugby ($n = 198$), soccer ($n = 194$), basketball ($n = 114$), skiing ($n = 62$), lacrosse ($n = 20$), and baseball/softball ($n = 20$) (Table 2).

Procedure and rehabilitation details

The technique utilized for tunnel drilling was reported in 18 studies. A transphyseal technique was reported to have

Table 2 Sports participation and patient characteristics

References	Sport and number of participants	Pre-operative sport level	Mean delay from injury to surgery (range), months	Open physis (*n*/total), tanner stages, bone age (mean)	Concomitant procedures
Calvo et al. [3]	NR	NR	3.8 months (range 0.5–17 months)	27/27 open physis Tanner stage II = 3 Tanner stage III = 6 Tanner stage IV = 18	NR
Cohen at al. [5]	NR	NR	5.4 months (0.5–48)	26/26 open physis Tanner stage I or II = 5 Tanner stage III = 9 Tanner stage IV = 12	Partial meniscectomy = 9 Meniscal repairs = 8
Cordasco et al. [6]	Soccer = 6 Skiing = 5 Lacrosse = 4	Competitive = 23	69.9 days (range 12–285 days)	Bone age: 12.2 years (range 11–15 years)	Meniscal debridement = 1 Meniscal repairs = 8
Chicorelli at el. [4]	Soccer = 70 Basketball = 40 Football/rugby = 33 Skiing/snowboarding = 13	NR	NR	NR	NR
Dekker et al. [9]	Baseball/softball = 8 Basketball = 30 Football = 9 Lacrosse = 3 Other = 5 Soccer = 24 Volleyball = 6	NR	NR	66/85 open physis	NR
Demange et al. [10]	NR	Competitive = 12	NR	12/12 open physis Tanner stage 1 and 2 = 12	Meniscal repairs = 1
Giudici et al. [8]	NR	NR	4 (range 2–32) weeks	19/19 open physis Tanner stage 2 or 3 = 19	Partial meniscectomy = 2 Meniscal repairs = 5
Goddard et al. [17]	Basketball = 3 Soccer = 9 Trampoline = 1 Netball = 2 Rugby = 8 Skiing = 1 Playground = 1 Motorbike = 2 Touch football = 1 Australian football league = 1 Athletics = 1 Cycling = 1 Gymnastics = 1	Competitive = 29	7 months (range 1 month–6 years)	24/29 open physis Tanner 1 or 2 = 15	Partial meniscectomy = 3 Meniscal repairs = 5

Table 2 (continued)

References	Sport and number of participants	Pre-operative sport level	Mean delay from injury to surgery (range), months	Open physis (*n*/total), tanner stages, bone age (mean)	Concomitant procedures
Graziano et al. [18]	Softball = 1 Soccer = 17 Lacrosse = 13 Basketball = 2 Baseball = 1 Football = 1 Ski racing = 4 Skateboard = 1 Running = 1	Competitive = 42	NR	NR	NR
Holwein et al. [21]	Running = 14 Inline Skating = 13 Hiking = 9 Climbing = 7 Cycling = 24 Swimming = 16 Fitness = 3 Gym = 10 Skiing = 21 Soccer = 28	Competitive = 42	4.2 months (range 0.9–20.6, SD ± 4.2)	42/42 open physis	Partial meniscectomy = 14 Meniscal repairs = 7
Hui et al. [22]	Soccer = 4 Motorcycle = 2 Playground = 2 Rugby = 2 Australian football league = 1 Basketball = 1 Cycling = 1 Skiing = 1 Trampoline = 1 Unknown = 1	Competitive = 16	Within 3 weeks of injury in 1 patient (6%), between 3 and 12 weeks in 8 (50%), and after 12 weeks in 7 (44%)	16/16 open physis Tanner stage 1 and 2 = 16	Meniscal repairs = 3
Jong et al. [24]	NR	NR	4.2 months (range 2–12)	11/11 open physis Tanner stage 1 and 2 = 11	NR
Larson et al. [26]	NR	NR	NR	29/29 open physis Tanner stage I = 5 Tanner stage II = 17 Tanner stage III = 7	Partial meniscectomy = 7 Meniscal repairs = 5
McCullough et al. [28]	Football = 29	NR	NR	NR	NR

Table 2 (continued)

References	Sport and number of participants	Pre-operative sport level	Mean delay from injury to surgery (range), months	Open physis (*n*/total), tanner stages, bone age (mean)	Concomitant procedures
Morgan et al. [31]	Rugby = 78 Soccer = 29 Netball = 36 Basketball = 22 Skiing = 17 Touch Football = 12 Hockey = 10 Gymnastics = 7 Motor Bike = 5 Other = 17	NR	Acute phase (within 3 weeks of injury) in 7 patients (3%), in the sub acute phase (3–12 weeks) in 166 patients (69%), and in the chronic phase (> 12 weeks) in 69 patients (28%)	NR	Partial meniscectomy = 78 Meniscal repairs = 20
Placella et al. [33]	Football = 14 Volleyball = 4 Basketball = 3 Cycling = 1 Dancing = 1 Fighting = 1	NR	NR	29/29 open physis Tanner 1 = 1 Tanner 2 = 3 Tanner 3 = 5 Tanner 4 = 12 Tanner 5 = 1	Partial meniscectomy = 5 Meniscal repairs = 7
Schmale et al. [35]	NR	NR	NR	29/29 open physis	NR
Shelbourne et al. [36]	Basketball = 10 Wrestling = 1 Ice hockey = 1 Volleyball = 2 Soccer = 2	Competitive = 16	NR	16/16 open physis Tanner stage 3 = 7 Tanner stage 4 = 9	Partial meniscectomy = 3 Meniscal repairs = 3
Wall et al. [39]	Football = 9 Soccer = 5 Basketball = 3 Bicycle = 2 Motorized vehicle = 2 Other = 6	NR	4.4 months (range 18 days–33 months)	Bone age = 11.8 ± 1.8 (8.5–14.0)	Partial meniscectomy = 2 Meniscal repairs = 6
Webster et al. [41]	NR	Competitive = 140	12 weeks (range 1–45 weeks)	NR	NR

NR not reported

been used for 683 patients (75%), while an all-epiphyseal technique was used in 226 patients (25%). The most commonly used graft types were hamstring autografts ($n=864$), allografts (including patellar tendon, tibialis anterior, and iliotibial) ($n=139$), bone patella-tendon-bone autografts ($n=108$), and living donor hamstring grafts ($n=45$). The criteria for returning to sport were reported by nine studies (45%). Four studies reported a timeframe for return to sporting activities with 3 allowing return between 6 and 9 month postoperatively [22, 31, 39], while one study delayed return to sport until 12 months postoperatively [17]. Two studies evaluated the quality of movements of the athletes and allowed to return when these were deemed safe with proper control and quality of sports-specific movements [6, 18]. Finally, four studies allowed return to sports when patients regained 90% strength symmetry in the reconstructed knee [3, 26, 33, 39] (Table 3).

Return to sport

The pooled rate of return to any sporting activities as reported in 18 studies ($n=852$) was 92.0% [95% CI 86.2–96.2, $I^2=78.21\%$ (66.1–86.0%), $Q=78.0$] (Fig. 2). The pooled rate of return to sport at the pre-injury level was reported in 19 studies ($n=1008$) as 78.6% [95% CI 70.7–85.7%, $I^2=85.8\%$ (79.3–89.5%), $Q=128.7$] (Fig. 3). For those that participated in competitive sports before the injury, the pooled rate of return to competitive level of sport was 81.0% [95% CI 62.3–94.4%, $I^2=92.2\%$ (87.0–95.3%), $Q=89.8$].

A subgroup analysis revealed a rate of return to any sport participation of 91% (95% CI 84–96%, $I^2=69.3\%$) for those reconstructed with hamstring tendon autografts (11 studies), while 80% (95% CI 66–91%, $I^2=86.5\%$) returned to their pre-injury level of play (10 studies). Those reconstructed using a transphyseal technique returned to any sport participation at a rate of 94% (95% CI 88–99%, $I^2=54.4\%$) (10 studies), and returned to pre-injury level of play at a rate of 82% (95% CI 72–90%, $I^2=79.3\%$) (12 studies). Following all-epiphyseal ACL reconstruction, adolescents returned to any sport participation at a rate of 91% (95% CI 83–96%, $I^2=8.4\%$) (four studies). In ACL reconstruction in patients 14 years old or younger, 98% (95% CI 94–100%, $I^2=37.6\%$) returned to some level of sport (5 studies). The remainder of the subgroups that were assessed had less than four studies in each group and were, therefore, not combined in a meta-analysis of proportions (Table 4).

Secondary outcomes

When reported, there were a total of 93 graft ruptures (13%) in 717 reconstructed knees and a rupture of the contralateral ACL in 91 (14%) of 652 knees. Correlation between earlier return to sport and graft rupture was reported in only one study [9]. This study used a Cox regression analysis to assess risk factors for subsequent ACL injuries and found a significant correlation with time to return to sport [hazard ratio 0.86 (95% CI 73–98%), $p=0.03$] [9]. Two studies reported correlation between return to high level sports and contralateral ACL rupture [9, 31]. Complications related to growth between the operative and non-operative limb were reported in 32 patients overall. Twenty-three patients had overgrowth of the operative leg; with three having a leg-length discrepancy greater than 20 mm, 6 between 7 and 19 mm, and 14 between 1 and 7 mm. Five patients had decreased growth of the operative limb with a discrepancy between 1 and 7 mm. Four patients had valgus ($n=1$) or varus ($n=3$) deformity of the operative limb between 3° and 4.5° (Table 5).

Discussion

The most significant finding in the present study was a very high rate of return to any sporting activity after ACL reconstruction in the pediatric population (92%), and a high rate of return to competitive level sports at the pre-injury level (81%). Unfortunately, this was associated with a relatively high graft rupture rate (13%) and injury to the contralateral ACL (14%).

The rate of graft rupture in young athletes undergoing ACL reconstruction has been reported to be as high as 20% [40]. High rates of re-injury have prompted concern over the early return to sports in young athletes after ACL reconstruction [9]. The present meta-analysis has identified a high rate of graft rupture (13%) as well as contralateral ACL injury in these athletes. This high rate of graft or contralateral ACL rupture following ACL reconstruction in this age group (close to 30% combined) highlights an important concern during rehabilitation for this population. Therefore, special precaution should be considered in children and adolescent athletes who undergo ACL reconstruction. However, the similar rates of graft and contralateral ACL rupture may suggest that underlying patients' predisposition to ACL injury or the high-risk activities with which these athletes are participating may be more relevant to graft rupture than the readiness of the reconstructed ligament to sustain these activities. This is supported by a 15-year follow-up study by Morgan et al. who noted that return to high-risk sports was a risk factor for contralateral ACL injury in young athletes that had undergone ACL reconstruction, while it was not found to be a significant risk factor for graft rupture in the operative knee [31].

Compliance in activity restriction is historically poor among this group [32]. Several re-ruptures in the present review were reported in patients who returned to sports pre-maturely against medical advice. Parent and caregiver

Table 3 Rehabilitation and return to sport protocol

References	Rehab protocol	Return to sport protocol used (i.e., criteria for return to sporting activities)
Calvo et al. [3]	Continuous passive motion, isometric exercises, and active mobilization Immediate full weight-bearing as tolerated, on two crutches First month = joint range of motion, muscle strengthening, and proprioception Stationary bike at the fourth week Running at the eighth week Meniscal repair = crutches maintained and knee flexion limited to 70° for 6 weeks	After achieving proper muscular conditioning, evaluated through isokinetic test (strength deficit < 10% compared with the contralateral limb), patients were able to return to contact sports
Cohen at al. [5]	NR	NR
Cordasco et al. [6]	Cryotherapy in the postanesthesia care unit Physical therapy on postoperative day 1 Weight-bearing as tolerated with a hinged knee brace locked in full extension unless concomitant procedures Range of motion limited from 0° to 90° for 4 weeks Focus on range of motion, quadriceps, hamstring, and hip abductor strengthening, neuromuscular control	Quality of movement assessment to address modifiable risk factors before RTS
Chicorelli at el. [4]	NR	NR
Dekker et al. [9]	NR	NR
Demange et al. [10]	Partial weight-bearing in the first week Full weight-bearing as tolerated > 1 week Immediate knee motion without knee braces	NR
Giudici et al. [8]	No weight-bearing for 4 weeks Partial and full weight-bearing at weeks 4 to 6 and week 7, respectively Passive ROM of 10°–60° at week 1, up to 80° at week 2, 100° at week 3, and 120° at week 4 Active ROM of 10 to 90 degrees at week 2, then full flexion and extension at week 4 Isometric exercises at month 1 Cycling, proprioception, exors-extensors strengthening, isotonic and isokinetic exercises at month 2 Proprioception and running at month 3	NR
Goddard et al. [17]	Full weight-bearing immediately Straight-line jogging at 6 weeks Sidestepping activities at 3 months Training for ball sports at 5 months	Full return to competitive ball sports delayed until 12 months
Graziano et al. [18]	Standard ACLR rehabilitation protocol for the first 12 to 16 weeks Months 3 through 6, working with a trainer affiliated with their athletic program By 6 months, expected to have strength to perform foundational movement patterns (squat, single-leg stance, forward step down, and single-leg bridge)	Quality of movement assessment was repeated until the athlete was deemed safe to return to sports with proper control and quality of sports-specific movements at 100% speed
Holwein et al. [21]	NR	NR
Hui et al. [22]	Immediate weight-bearing with crutches Full extension by 14 days Closed-chain exercises, proprioceptive training	Return to competitive sport involving jumping, pivoting, or sidestepping was not permitted until 6–9 months after surgery depending on adherence to the rehabilitation protocol and achievement of postoperative goals
Jong et al. [24]	NR	NR

Table 3 (continued)

References	Rehab protocol	Return to sport protocol used (i.e., criteria for return to sporting activities)
Larson et al. [26]	Brace only at night for 1 week Crutches with protected weight-bearing for 3 weeks Light jogging at 4–5 months Return to athletic activities between 6 and 8 months after surgery	90% sided to side single-leg hop, triple hop, and restoration of jump landing and pivoting mechanics were required before resumption of more advanced sport-specific activities
McCullough et al. [28]	NR	NR
Morgan et al. [31]	Full weight-bearing immediately Early accelerated rehabilitation	Return to competitive sports involving pivoting and sidestepping activities at 6–9 months according to an objective assessment of whether the rehabilitation goals had been met
Placella et al. [33]	Immobilized in extension brace for 10 days No weight-bearing for 21 days Then, partial bearing with two crutches for 5 days and with one crutch for 4 days Full weight-bearing after 30 days Isometric exercises as soon as possible Knee flexion on the 10th postoperative day If the menisci were sutured, weight-bearing was forbidden for 1 month	Playing sports was allowed only after biomechanical examinations confirmed a good muscular and articular functional recovery in isokinetic and kinematic tests
Schmale et al. [35]	NR	NR
Shelbourne et al. [36]	First week = range of motion, while bed rest, elevation, and cold/compression > 1 week = increase knee range of motion and quadriceps muscle control Once full range of motion achieved, leg-strengthening program started, then functional progression program until return to sports	NR
Wall et al. [39]	Knee immobilizer for 1 week and weight-bearing as tolerated > 1 week physical therapy started Crutches discontinued at 2 to 4 weeks	Return to sports was allowed approximately 6–9 months postoperatively after the patient had regained 85–90% strength symmetry on Biodex (Biodex Medical Systems) testing and passed hop and agility tests
Webster et al. [41]	NR	NR

NR not reported

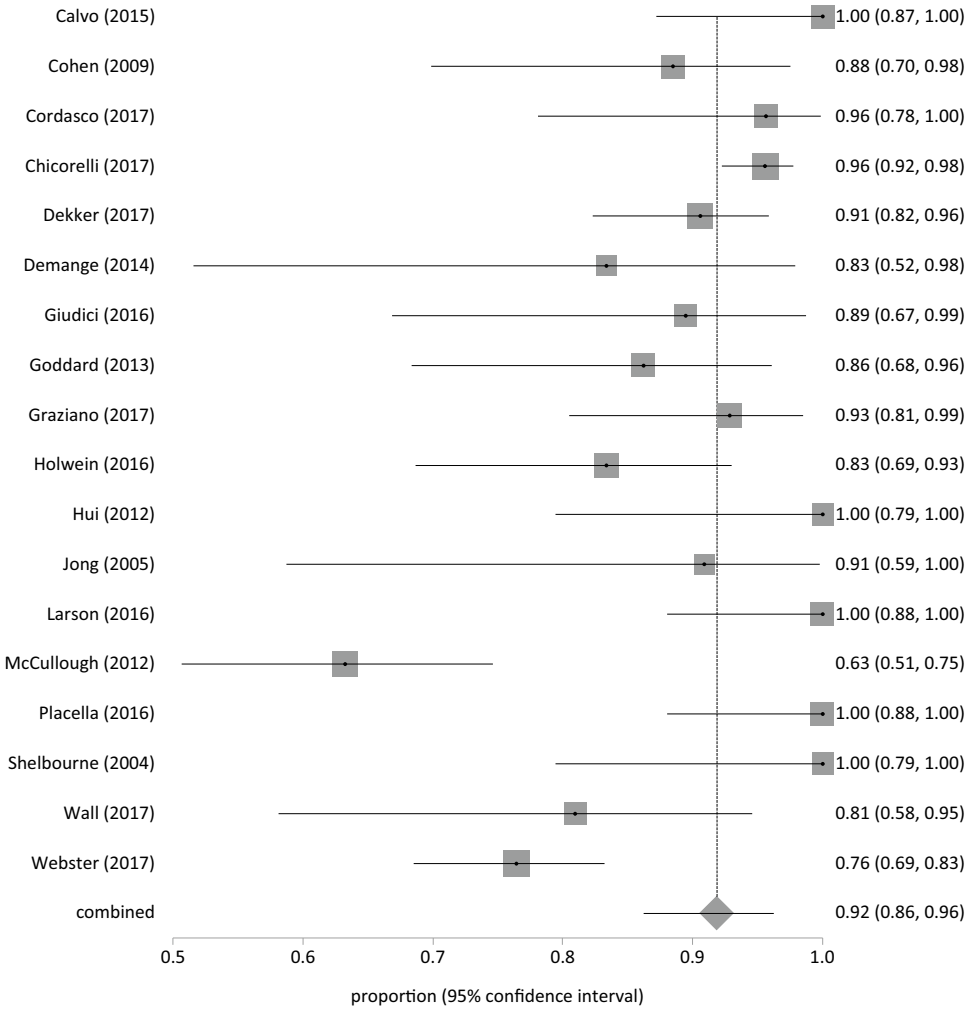

Fig. 2 Forest plot demonstrating a pooled rate of return to any level of sport of 92% after ACL reconstruction in children and adolescents based on the reported rates in 18 studies combined using a random-effects model

education and close observation and monitoring to ensure these patients are adhering to activity restrictions is critical given the high rates of re-injury and inherently poor compliance in activity restriction.

There is currently a lack of universal guidelines in terms of optimal rehabilitation and return to sport protocols after ACL reconstruction in the pediatric population [32]. Adherence to similar return to sport timelines as per adult patients is complicated by the fact that some pediatric patients may have significant muscle deficits for more than a year after ACL reconstruction and may benefit from a more prolonged rehabilitation [19]. It is imperative that specific return to sport criteria are used and followed by the patients undergoing ACL reconstruction to ensure readiness to return and limit the rate of re-injury [18]. Criteria that have been reported in the literature include a battery of tests aimed at measuring impairments in strength and power of the leg, examination of proactive and reactive activities simulating a real-case sport activity scenario, as well as psychometric assessments [7]. Less than half of the included studies reported specific criteria that patients were required to meet before returning to sports. While definitive guidelines are lacking, particularly for patients of this age group, recent studies have investigated individualized programs and targets for young athletes using quality of movement assessments [6, 18].

A previous systematic review and meta-analysis of 69 studies by Ardern et al. assessed the rate at which individuals of all ages (mean 25.8, SD 3.2 years) return to sport following ACL reconstruction. Eighty-one percent returned to any sport, 55% returned to competitive sports, and 65% returned to their pre-injury level of competition [2]. These rates are lower than the corresponding rates of 92, 81, and 79%, respectively, identified in the present meta-analysis. Younger athletes are likely more determined to return to sporting activities, and have fewer commitments such as work and family restricting their return to sports.

A meta-analysis of 55 studies by Frosch et al. assessed the clinical outcomes after ACL reconstruction in children and adolescents [16]. The rate at which the athletes returned to sports was not assessed by this study; however, it was found that the overall rate of growth disturbances after ACL

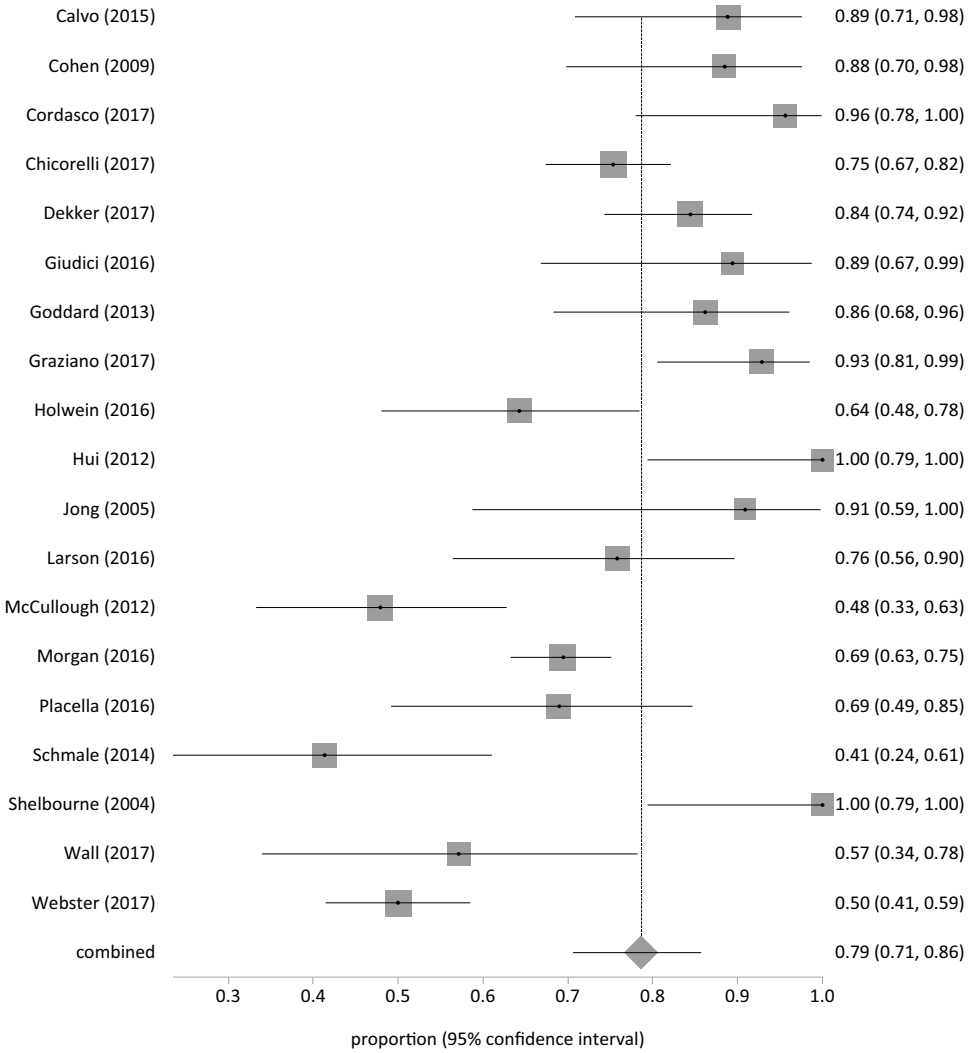

Fig. 3 Forest plot demonstrating a pooled rate of return to the pre-injury level of sport of 79% after ACL reconstruction in children and adolescents based on the reported rates in 19 studies combined using a random-effects model

reconstruction in this population was less than 2%, similar to the growth disturbance rate of 2.7% identified in the present systematic review. It was found that those reconstructed with a transphyseal technique and with hamstring tendon autografts had lower rates of growth disturbances but a higher rate of graft re-rupture than those who had an epiphyseal technique or bone patellar tendon-bone. However, the rate of growth disturbance was much higher in Fauno et al. who reported on the results of transphyseal ACLR using hamstring autograft without intraosseous-placed fixation implants in pediatric patients (mean 11.7 years, range 9.0–14.0 years) and found more than 10 mm of shortening of the operated leg in 24%, and a change in anatomic femoral axis in 82% of the patients [14].

Finally, it is important to note that studies on return to play after ACL reconstruction have inherent bias as factors other than the patients reconstructed knee may affect whether they return to sport and at which level. For instance, they may be entering a period of transition where they do not have the ability to move to the next level of play or their priorities change such as those entering post-secondary education. Other factors that limit the ability of young athletes to return to sport are psychological factors, primarily the fear of re-injuring the reconstructed ACL [38].

This systematic review and meta-analysis is limited by the quality of the studies that were included for assessment. These studies were primarily retrospective observational studies, without control groups for comparison or randomized designs to limit bias. Other potential biases included differences across studies in terms of the sport and level of participation. Furthermore, various graft types were used and different techniques used for tunnel drilling and graft fixation creating a somewhat heterogeneous group. Moreover, most studies did not report the different rates of return to sporting activities for patients in separate groups. As such, this meta-analysis could not compare the rates of return to sport for children and adolescents reconstructed with different methods, or those participating in different level and types of sports. However, subgroup analyses of the return to sport rates were conducted wherever possible. There was

Table 4 Return to sport outcomes

References	Number of patients returning to sport at any level (of total patients)	Time to return to sport at any level (range), months	Number of patients returning to sport at pre-operative level (of total patients)	Time to return to sport at pre-operative level (range), months	Number of patients returning to competitive sport (of those who participated in competitive sports)	Time to return to competitive sport (range), months
Calvo et al. [3]	27/27	NR	24/27	NR	NR	NR
Cohen at al. [5]	23/26	NR	23/26	NR	NR	NR
Cordasco et al. [6]	22/23	13.5 (8–22)	22/23	13.5 (8–22)	22/23	13.5 (8–22)
Chicorelli at el. [4]	239/250	9 ± 1	107/142	NR	NR	NR
Dekker et al. [9]	77/85	9.6 ± 3.2 (2 to 24)	65/77	9.6 ± 3.2 (2 to 24)	NR	NR
Demange et al. [10]	10/12	NR	NR	NR	5/12	NR
Giudici et al. [8]	17/19	6	17/19	6	NR	NR
Goddard et al. [17]	25/29	NR	25/29	NR	25/29	NR
Graziano et al. [18]	39/42	12 ± 2	39/42	12 ± 2	39/42	12 ± 2
Holwein et al. [21]	35/42	NR	27/42	NR	23/42	NR
Hui et al. [22]	16/16	NR	16/16	NR	16/16	NR
Jong et al. [24]	10/11	NR	10/11	NR	NR	NR
Larson et al. [26]	29/29	NR	22/29	NR	NR	NR
McCullough et al. [28]	43/68	NR	23/48	NR		
Morgan et al. [31]	NR	NR	168/242	NR	NR	NR
Placella et al. [33]	29/29	6.43 months (range 4 months and 25 days to 7 months and 23 days)	20/29	6.43 months (range 4 months and 25 days to 7 months and 23 days)	NR	NR
Schmale et al. [35]	NR	NR	12/29	NR	NR	NR
Shelbourne et al. [36]	16/16	NR	16/16	NR	16/16	NR
Wall et al. [39]	17/21	NR	12/21	NR	NR	NR
Webster et al. [41]	107/140	NR	70/140	NR	70/140	NR

NR not reported

also significant heterogeneity across studies, measured using the I^2 statistic, which gives us less confidence in the pooled results. However, the rates were combined using a random-effects model in a meta-analysis of proportions to account for these differences.

Despite the limitations, the findings in this systematic review are important for orthopedic surgeons managing ACL injuries in children and adolescents. For these young athletes in consideration for ACL reconstruction, an important outcome is the ability to return to sport participation. This review summarizes the literature that is available to provide the clinicians and patient families with an up to date, evidence-based review on peer-reviewed data pertaining to the ability to return to sport after ACL reconstruction in this population. We recommend that clinicians use the information presented in the current systematic review and meta-analysis (within its limitations) to supplement the informed-consent process while coming up with a decision on the management of ACL injuries in children and adolescents.

Future research should use high-quality prospective study designs to compare the different techniques that are used for ACL reconstruction in children and adolescents to create a standardized, validated, and easy-to-adhere to rehabilitation and return to sport protocol in this group to ensure optimal outcomes while minimizing the risk of re-injury. Furthermore, preventative programs that may be able to limit the number of index, graft, or contralateral injuries should be sought out and assessed.

Table 5 Surgical details and secondary outcomes

References	ACL graft ruptures (*n*/total)	Contralateral ACL ruptures	Graft type used	Surgical approach for drilling the femoral tunnel (transphyseal/physeal-sparing)	Correlations reported between return to sport and revision rates	Complications
Calvo et al. [3]	4/27	NR	Semitendinosus-gracilis autograft	Transphyseal	3/4 sports related at months 7, 35, and 99 postoperatively, respectively	There was no significant difference in the length of the lower extremities on radiographic evaluation
Cohen at al. [5]	3/26	NR	Autogenous quadruple hamstrings graft	Transphyseal	1/3 occurred during sports participation at 4 months against medical advice 2/3 occurred during sport participation more than 1 year postoperatively	The length of the operated limb was decreased compared with the contralateral limb in only 5 patients. The mean length difference in the patients with decreased operated limb length was 3.6 mm (range 2.0–7.0 mm). Eight patients had no difference in the lengths of their lower limbs. In 13 patients, the length had increased by 3.9 mm (range 1–7 mm)
Cordasco et al. [6]	1/23	1/23	Hamstring autograft	All- epiphyseal reconstruction	Not sports related. Not cleared for return to sports when injury occurred	11 were noted to have a small proximal tibial physeal disturbance by the tibial socket, the violation was less than 5% of the surface. 6 of these had a leg-length discrepancy of more than 5 mm (range 6–18 mm); however, the overgrowth was in the femur in all patients
Chicorelli at el. [4]	NR	NR	Autologous hamstring = 135 Iliotibial band = 72 Patellar tendon = 31 Tibialis anterior allograft = 12	Extraphyseal or transphyseal	NR	NR
Dekker et al. [9]	16/85	11/85	Hamstring autograft = 62 Patellar tendon autograft = 13 Hamstring autograft with allograft augment = 10	Adult-type reconstruction = 56 Vertical transphyseal reconstruction = 12Physeal preserving (partial transphyseal or all-epiphyseal) = 15	Longer times prior to return to sport were protective against a second ACL injury, either ipsilateral or contralateral (HR per month, 0.87 [95% CI 0.73 to 0.99] for each 1-month increase; $p = 0.04$)	NR
Demange et al. [10]	3/12	NR	Double-stranded semitendinosus grafts	Transphyseal (tibia) Physeal-sparing (femur)	3/3 sports related injuries No specific correlation identified in terms of timing of return to sports	There were no superficial or deep infections, deep vein thrombosis, nerve injuries, arthrofibrosis, or other perioperative complications. During the follow-up, there were no leg-length discrepancies or radiographic premature closure of growth plates

Table 5 (continued)

References	ACL graft ruptures (*n*/total)	Contralateral ACL ruptures	Graft type used	Surgical approach for drilling the femoral tunnel (transphyseal/physeal-sparing)	Correlations reported between return to sport and revision rates	Complications
Giudici et al. [8]	2/19	0/19	Double hamstring tendon graft	Transphyseal	No correlation Both re-ruptures in patients who were not able to return to sports at their pre-injury level	Two patients had reduced sensitivity in the anteromedial aspect of the proximal third of the tibia One patient had leg-length discrepancy of + 1.5 cm (but no complaint of any limitation in his professional lifestyle, a discrepancy of 2 cm is considered clinically relevant)
Goddard et al. [17]	2/32	0/32	Living donor hamstring tendon allograft	Transphyseal	½ of the re-ruptures occurred during sporting activities	None
Graziano et al. [18]	4/42	2/42	Hamstring tendon autograft	Physeal-sparing	4 had been cleared to return to sports, while 2 returned against medical advice. 50% occurred within first 12 months of surgery	None of the athletes had a significant growth disturbance (> 1.5-cm change) on follow-up imaging (standing radiographs and SPGR MRI analysis)
Holwein et al. [21]	3/42	2/42	Hamstring tendon autograft	Transphyseal	3/3 during sporting activities, 2 earlier than 1 year postoperatively	None had leg-length discrepancy more than 1 cm Three patients showed varus (1) or valgus (2) malalignment between three degrees and 4.5°
Hui et al. [22]	0/16	0/16	Living donor-related hamstring tendon allograft ($n = 14$), hamstring tendon autograft ($n = 1$), and fresh-frozen allograft ($n = 1$)	Transphyseal	No correlation	None
Jong et al. [24]	0/11	0/11	Hamstring tendon autograft	Transphyseal	No correlation	Limb length discrepancy was evaluated at the final follow-up by orthoroentgenography, at which time no case presented with a discrepancy of more than 1 cm
Larson et al. [26]	5/29	5/29	Quadrupled hamstring autograft = 22 Tibialis anterior allograft = 8	Transphyseal	5/5 during sporting activities after cleared for return to sports at a mean of 24 months (10–34 months) postoperatively	1 case of distal femoral physeal closure, resulting in secondary valgus deformity
McCullough et al. [28]	NR	NR	Hamstring graft = 12 Soft tissue allografts = 5	NR	NR	NR
Morgan et al. [31]	42/252	48/252	Hamstring tendon = 194 Patellar tendon = 48	Transphyseal	No correlation between returning to high level of sports and ACL graft failure Those who return to high level are at increased risk of rupturing contralateral ACL	NR

Table 5 (continued)

References	ACL graft ruptures (*n*/total)	Contralateral ACL ruptures	Graft type used	Surgical approach for drilling the femoral tunnel (transphyseal/physeal-sparing)	Correlations reported between return to sport and revision rates	Complications
Placella et al. [33]	0/29	10/29	Quadrupled gracilis tendon grafts	Transphyseal	No correlation reported	No resurgery due to growth abnormalities was required. The mean difference in length between the operated and contralateral legs was 0.4 (range − 0.2 to 0.7) cm. None of the patients reported problems related to discrepancies in limb length
Schmale et al. [35]	4/29	8/29	Quadruple-stranded hamstring auto- graft or a double-stranded fresh-frozen nonirradiated tibialis anterior allograft	Transphyseal	No correlation between activity level and risk of re-operation	4/29 repeat arthroscopy for arthrofibrosis There were no reoperations for growth abnormalities, and no angular malalignments or radiographic anomalies were appreciated by clinical or radiographic examination at the study follow-up
Shelbourne et al. [36]	1/16	2/16	Patellar tendon autograft	Transphyseal	No correlation between activity level and risk of re-operation	None of the patients had any gross leg deformities or leg-length discrepancies. Radiographs revealed that none of the patients had growth plate disturbance, angular deformities, or medial or lateral joint space narrowing
Wall et al. [39]	3/27	2/27	Quadruple-hamstring tendon graft	All-epiphyseal	Occurred within 1.5 years of initial surgery	There were no cases of bony growth arrest or bone undergrowth. Although no patients exhibited growth arrest Overgrowth (> 2 cm) was identified in 3 patients, 2 requiring surgical correction
Webster et al. [41]	NR	NR	Hamstring tendon autograft	NR	NR	NR

NR not reported

Conclusion

Pooled results suggest a high rate of return to sport following ACL reconstruction in children and adolescent athletes; however, this is associated with a relatively high rate of graft rupture and a similar rate of contralateral ACL injury.

Compliance with ethical standards

Conflict of interest The authors declare no competing financial interest.

Funding None.

Ethicalapproval This is a systematic review of the literature and no ethics approval is required.

Informed consent Informed consent was not applicable to this study.

Appendix

See Table 6.

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Table 6 Search strategy

EMBASE: 319 studies		MEDLINE: 768 studies		PubMed: 2491 studies	
Strategy	Studies	Strategy	Studies	Strategy	Studies
1. Anterior cruciate ligament reconstruction/or anterior cruciate ligament/or acl.mp	23,366	1. Anterior Cruciate Ligament Injuries/or Anterior Cruciate Ligament/or acl.mp. or Anterior Cruciate Ligament Reconstruction	19,961	1. ACL or (anterior cruciate ligament)	25,159
2. Adolescent/	1,437,910	2. Pediatric.mp. or Pediatrics	274,650	2. Pediatric or adolescent or child or (skeletally immature)	3,234,182
3. Skeletally immature.mp	1540	3. Adolescent/or adolescent.mp	1,929,464	3. Sport or (return to sports)	261,121
4. Child/	1,501,754	4. Child/or skeletally immature.mp	1,597,200	4. 1 AND 2 AND 3	2491
5. Return to sport.mp. or return to sport/or sport/	44,722	5. 2 or 3 or 4	2,769,018		
6.2 or 3 or 4	65,001	6. Sports/or sports.mp. or Youth Sports	72,553		
7. 1 and 2 and 6	319	7. Return to sports.mp. or Return to Sport	1393		
		8. 6 or 7	72,787		
		9. 1 and 5 and 8	768		

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