Return to Sport After ACL Reconstruction With a BTB Versus Hamstring Tendon Autograft

A Systematic Review and Meta-analysis

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Background: Anterior cruciate ligament (ACL) tears are debilitating injuries frequently suffered by athletes. ACL reconstruction is indicated to restore knee stability and allow patients to return to prior levels of athletic performance. While existing literature suggests that patient-reported outcomes are similar between bone–patellar tendon–bone (BTB) and hamstring tendon (HT) autografts, there is less information comparing return-to-sport (RTS) rates between the 2 graft types.

Purpose: To compare RTS rates among athletes undergoing primary ACL reconstruction using a BTB versus HT autograft.

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

Methods: The MEDLINE, Embase, and Cochrane Library databases were searched, and studies that reported on RTS after primary ACL reconstruction using a BTB or HT autograft were included. Studies that utilized ACL repair techniques, quadriceps tendon autografts, graft augmentation, double-bundle autografts, allografts, or revision ACL reconstruction were excluded. RTS information was extracted and analyzed from all included studies.

Results: Included in the review were 20 articles investigating a total of 2348 athletes. The overall RTS rate in our cohort was 73.2%, with 48.9% returning to preinjury levels of performance and a rerupture rate of 2.4%. The overall RTS rate in patients after primary ACL reconstruction with a BTB autograft was 81.0%, with 50.0% of athletes returning to preinjury levels of performance and a rerupture rate of 2.2%. Patients after primary ACL reconstruction with an HT autograft had an overall RTS rate of 70.6%, with 48.5% of athletes returning to preinjury levels of performance and a rerupture rate of 2.5%.

Conclusion: ACL reconstruction using BTB autografts demonstrated higher overall RTS rates when compared with HT autografts. However, BTB and HT autografts had similar rates of return to preinjury levels of performance and rerupture rates. Less than half of the athletes were able to return to preinjury sport levels after ACL reconstruction with either an HT or BTB autograft.

Keywords: bone–patellar tendon–bone autograft; hamstring tendon autograft; allograft; return to sport; anterior cruciate ligament rupture; anterior cruciate ligament reconstruction

Anterior cruciate ligament (ACL) tears or ruptures are one of the most common knee injuries seen in an athletic population. The exact number of ACL reconstruction procedures performed in the United States is unknown; however, Herzog et al,[22] using the MarketScan database with approximately 158 million privately insured patients, reported that 283,810 ACL reconstruction procedures were performed between 2002 and 2014. The overall rate increased 22% from 61.4 per 100,000 person-years in 2002 to 74.6 per 100,000 person-years in 2014. An ACL tear is a devastating, season-ending injury, with only 51% of athletes returning to sport without restrictions at 6 months postoperatively.[12,21] While methods describing the repair of a ruptured ACL are emerging along with different options for graft choices,[18] surgical reconstruction of the ACL using autografts in young athletes remains the standard of care. However, autograft selection is still an ongoing topic of debate in the sport medicine literature and among orthopaedic sports medicine surgeons.

The most commonly used autografts are (1) bone–patellar tendon–bone (BTB) grafts harvested typically from the middle third of the ipsilateral patellar tendon or (2) hamstring tendon (HT) grafts harvested from the semitendinosus and gracilis tendons. There are advantages and disadvantages as well as morbidity associated with each of these autograft options. Compared with patients receiving HT autografts, those who receive BTB autografts may experience more anterior knee pain resulting from donor site pain and a larger incision at the time of harvest as well as possible extensor strength deficits.[20,41,46,55] In comparison, HT

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autografts have been associated with prolonged hamstring or knee flexion weakness, saphenous nerve damage, and sensory loss.[8,20,28] The HT autograft may also be susceptible to stretching over time, weakening its ability to maintain objective rotational stability of the knee postoperatively.

The primary goal of ACL reconstruction in the young athletic population is to stabilize the knee for returning to prior levels of sport participation. While the literature suggests that there are no major differences between BTB and HT autografts with respect to clinical outcomes,[9,49] less information exists comparing the rate of return to sport (RTS) between these 2 graft types. A study by Mascarenhas et al[35] found that 70% of young athletes who had either a BTB or HT autograft were able to return to strenuous or very strenuous sporting activity. However, only 57% of patients with a BTB autograft and 44% of patients with an HT autograft were able to return to preinjury levels of performance. A 2018 systematic review also found that while the majority of elite athletes return to their prior level of sport, performance declines in comparison with preinjury levels. Furthermore, the authors found limited available literature on RTS after ACL reconstruction in terms of sport-specific performance after ACL surgery.[37] Therefore, determining which autograft type provides superior RTS may aid surgeons and patients in shared decision making and setting of expectations for both functional outcomes and expected RTS rates after ACL reconstruction. The objective of this systematic review and meta-analysis was to compare the rates of overall RTS, return to preinjury levels, and reruptures between athletes who have undergone primary ACL reconstruction using a BTB versus HT autograft.

METHODS

Search Strategy

A systematic search strategy was developed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[36] The goal of the search was to identify articles that report on RTS after primary ACL reconstruction with an autograft. A search of electronic databases was performed to find potentially relevant research articles reporting on RTS after ACL reconstruction. The MEDLINE (PubMed), Embase (Elsevier), and Cochrane Library databases were searched in October 2018 using the following Boolean search terms: (((ACL reconstruction) or (anterior cruciate ligament reconstruction) or (ACL tear) or (anterior cruciate ligament tear) or (Bone Patella Tendon Bone) or (hamstring) or (BTB) AND ((return to sports) or (return to preinjury activity) or (athlete) or (athletics) or (athletic population) or (athlete population) or (return to competition) or (return to athletics))). In order to maximize sensitivity, no filters were applied.

Eligibility Criteria

All search results were extracted and examined for relevance, and duplicate articles were discarded. Titles and abstracts were then screened for relevance. Bibliographies of relevant articles were also manually searched to find other pertinent articles that were screened out of the database algorithms. Articles were filtered based on the following exclusion criteria: (1) non-English text, (2) not athlete-specific population, (3) only abstract available, (4) did not quantify RTS outcomes, (5) treatment was nonsurgical or did not specify which graft (HT or BTB) was used, (6) studies included multiple treatments without stratifying by operation type, (7) surgical treatment was on skeletally immature patients, (8) patients were treated with allografts, (9) studies were on revision ACL reconstruction, (10) review articles or meta-analyses, and (11) case reports. We made the decision to include non–randomized controlled trials for this meta-analysis because of the scarcity of published randomized controlled trials available for this topic. Only studies that included RTS rates centering on a single surgical procedure, or studies that specifically stratified mixed patient populations or surgical treatments, were evaluated. Because of the limited RTS data after ACL reconstruction with double-bundle HT grafts, the decision was made to include only primary ACL reconstruction with single-bundle HT autografts in this analysis. Of note, there were 2 studies conducted by Ardern et al[3,5] that utilized the same cohort at 2 different follow-up periods, and only the more recent study with longer follow-up, published in 2012, was included in our final analysis.[3]

Article Review

After the screening phase, all eligible articles were evaluated for inclusion criteria and relevant data on RTS and outcomes after ACL reconstruction. All articles were reviewed, assessed, and data-mined by 2 independent evaluators (M.D. and M.J.G.). All results were then compared to ensure consistency and accuracy. Any conflicts or issues

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were resolved by a review of the articles, and the senior author (X.L.) made the final determination.

Data Extraction and Assessment

Articles that met inclusion criteria were analyzed for quality, and data to be used in the review were extracted. The following items were extracted from the included articles: author, publication year, journal title, level of evidence, study design, surgical procedure, number of athletes, type of sport, number of participants per sport type, level of athletic participation, mean age at the time of surgery, sex, mean follow-up period, concomitant procedures, percentage of athletes who returned to sport, percentage of athletes who returned to preinjury levels of sport, and subsequent procedures needed. Studies including multiple graft types were stratified and analyzed by graft type independently.

Quality Assessment

To assess the quality of each case series study that was included in the analysis, the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool was utilized.[50] This risk-of-bias tool includes 7 criteria: (1) bias due to confounding, (2) bias in selection of participants into the study, (3) bias in classification of interventions, (4) bias due to deviations from intended interventions, (5) bias due to missing data, (6) bias in measurement of outcomes, and (7) bias in selection of the reported result. Each criterion was rated as *low risk*, *moderate risk*, *serious risk*, or *critical risk* in accordance with the ROBINS-I tool.[47]

Statistical Analysis

Studies that reported the rates of RTS, return to preinjury levels of play, and reruptures for both BTB and HT grafts were included in the meta-analysis. The meta-analysis was conducted using R V 3.5.2 (The R Foundation) and formatted with Review Manager 5 (RevMan; Cochrane Collaboration). This package summarized data to create appropriate forest plots for graphical presentation. A random-effects model was used to reduce bias from the potential systematic errors of the included studies, and the inverse variance method was used for the weighting of each study. Continuity correction of 0.5 was used in studies with zero cell frequencies. Homogeneity across the studies was assessed and represented by I^2, with $P < .05$ being statistically significant.

RESULTS

Individual Study Characteristics

A total of 20 studies met inclusion criteria and were included in the final analysis (Figure 1). In terms of levels of evidence, in the BTB group, there were two level 4 studies,[10,33] five level 3 studies,[16,19,25,35,43] one level 2 study,[48] and three level 1 studies[14,26,47] (Table 1). Table 1 shows the demographic and RTS data after primary ACL reconstruction with BTB autografts. Appendix Table A1 shows the type of sport played, concomitant procedures, and revision surgery for ACL reconstruction with BTB autografts. In the HT group, there was one level 5 study,[38] six level 4 studies,[10,29,31,33,40,52] six level 3 studies,[3,11,17,19,35,43] one level 2 study,[48] and four level 1 studies[14,26,34,47] (Table 2). Table 2 shows the demographic and RTS data after primary ACL reconstruction with HT autografts. Appendix Table A2 shows the type of sport played, concomitant procedures, and revision surgery for ACL reconstruction with HT autografts.

There were 2 studies that reported the RTS rate for BTB grafts but not the rate of return to preinjury levels,[10,43] and 2 studies only reported the rate of return to preinjury levels but not the rate of RTS overall.[16,48] There were 5 studies that reported on RTS for HT grafts but did not comment on return to prior levels of sport participation.[10,11,29,38,43] In 3 of the studies, only return to prior levels of play was reported, but overall RTS was not reported.[17,31,48]

Overall, there were 9 studies that reported RTS data for both BTB and single-bundle HT autografts,[#] 2 studies that reported RTS data for BTB autografts only without HT grafts as a comparison group,[16,25] and 9 studies that reported RTS data for HT autografts only without BTB grafts as a comparison group.[**] Moreover, 8 of the 9 studies directly comparing BTB versus HT autografts reported on the rate of RTS, with none finding a statistically significant difference in RTS between grafts in their cohorts.[10,14,19,26,33,35,43,47] Further, 7 of the 9 studies reported on return to preinjury levels[14,19,26,33,35,47,48]; no statistically significant difference in the rate of return to preinjury levels was found in any study.

Pooled Analysis

A total of 2348 patient-athletes who underwent ACL reconstruction were included in the studies reviewed, of which 610 patients received BTB autografts and 1738 patients received HT autografts (single-bundle). The pooled RTS data are summarized in Table 3. All included studies reported a minimum mean follow-up of 1 year.

Studies examining RTS after ACL reconstruction with BTB grafts demonstrated a range of rates from 69% to 94%, with a mean rate of 81.0% for all patients. However, only 50.0% of all patients were able to return to their prior level of play.

The studies that reported on RTS after ACL reconstruction with HT grafts showed a wider range of rates, from 48% to 93%, with a mean rate of 70.6% for all patients. Across studies, 48.5% of patients returned to their prior level of sport participation.

In subgroup analyses of the level 1 and 2 studies for BTB and HT autografts included in this review, the results remained consistent with whole-group pooled analysis. In the BTB group (4 studies[14,26,47,48]), the rates of RTS and return to preinjury sport levels were 81.8% and 57.1%, respectively. In the HT group (5 studies[14,26,34,47,48]), the

[#]References 10, 14, 19, 26, 33, 35, 43, 47, 48.

**References 3, 11, 17, 29, 31, 34, 38, 40, 52.

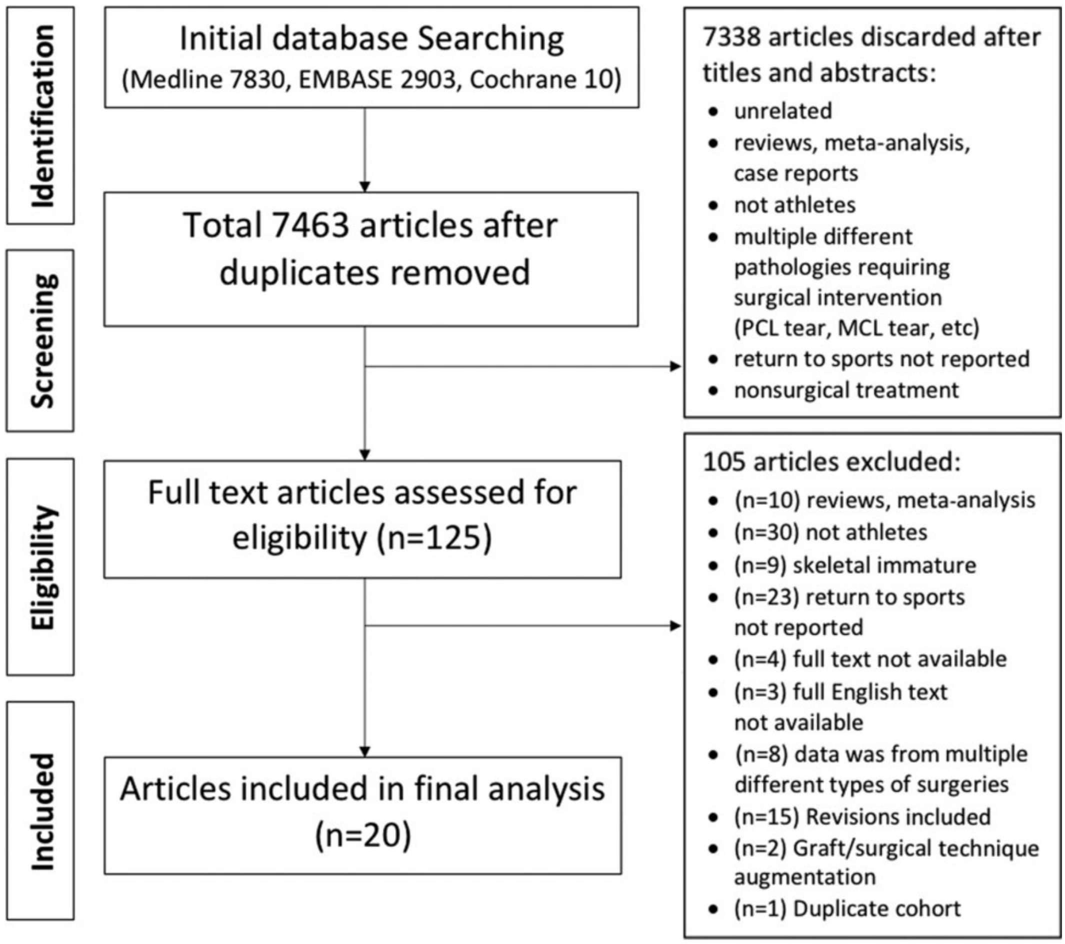

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow chart indicating research article inclusion for final analysis. MCL, medial collateral ligament; PCL, posterior cruciate ligament.

rates of RTS and return to preinjury levels of sport were 74.8% and 52.7%, respectively.

Quality Assessment

The risk-of-bias assessment is summarized in Table 4 and Figure 2. Of the 16 assessed studies, 15 studies had serious or moderate bias due to confounding factors such as differing concomitant injuries/procedures, levels of competition, or sports played. Also, 5 of the 16 included studies had some risk of bias owing to missing data, specifically from patients lost to follow-up. Furthermore, all studies had some risk of bias in terms of outcome measures, as RTS is often a subjective measure. A limitation with several of these studies was that they reported RTS data based on graft type but did not separate the patient demographic data for each individual graft type during the analysis.[10,33,43]

Meta-analysis

Of the 20 studies identified for the systematic review, the following subset of studies evaluated outcomes for both BTB and HT grafts: 5 studies for RTS,[10,14,26,35,47] 7 studies for return to preinjury levels of play,[14,19,26,33,35,47,48] and 3 studies for ACL reruptures.[14,19,47] The relative risks of developing an unfavorable outcome after ACL reconstruction with BTB grafts compared with HT grafts were as follows: inability to return to sport: 0.85 (95% CI, 0.55-1.32); inability to return to preinjury levels of play: 0.98 (95% CI, 0.82-1.16); and ACL reruptures: 0.67 (95% CI, 0.12-3.60) (Figures 3-5). No statistical significance was detected. The I^2 index of homogeneity was 0% for 3 of 3 meta-analyses, suggesting that the included studies were homogeneous; however, this may also represent that all studies were underpowered to detect a difference in outcomes.

DISCUSSION

The overall rate of RTS was 73.2%, but the BTB group had a 10.4% higher overall rate of RTS (81.0%) compared with the HT group (70.6%). Importantly, these findings were consistent with our subanalysis of RTS rates from level 1 and 2 studies only, with BTB and HT autografts demonstrating RTS rates of 81.8% and 74.8%, respectively.

TABLE 1
Demographic and RTS Data for Studies With BTB Autografts[a]

First Author (Year)	LOE	No. of Athletes	Age at Surgery, y	M:F Sex, n	Follow-up, mo	RTS Rate, % (n)	Rate of Return to Preinjury Levels, % (n)	Rerupture Rate, % (n)
Gobbi[16] (2002)	3	40	25	26:14	46 (36-62)	NR	60 (24/40)	0 (0/40)
Shaieb[47] (2002)[b]	1	33	32 (14-48)	26:7	>24	88 (29/33)	55 (18/33)	6 (2/33)
Feller[14] (2003)[b]	1	26	25.8 ± 6	NR	36	69 (18/26)	54 (14/26)	4 (1/27)
Jennings[25] (2003)	3	50	30 (17-51)	32:18	62 (48-95)	94 (47/50)	32 (16/50)	0 (0/50)
Mascarenhas[35] (2012)[b]	3	23	18 ± 3	10:13	60 ± 24	74 (17/23)	57 (13/23)	NR
Daruwalla[10] (2014)[b]	4	140	NR	140:0	>12	84 (117/140)	NR	NR
Kautzner[26] (2015)[b]	1	39	NR	0:39	24	87 (34/39)	49 (19/39)	5 (2/39)
Sandon[43] (2015)[b]	3	22	NR	NR	NR	73 (16/22)	NR	NR
Sonnery-Cottet[48] (2017)[b]	2	85	22 ± 4	NR	39.2 ± 8.8 (24-54)	NR	64 (54/85)	NR
Liptak[33] (2017)[b]	4	72	NR	72:0	NR	72 (52/72)	45 (19/42)	NR
Gupta[19] (2018)[b]	3	80	24 (18-44)	74:6	61.1 ± 25.8	79 (63/80)	40 (32/80)	1 (1/80)

[a]Data are presented as mean, mean ± SD, mean (range), or mean ± SD (range) unless otherwise specified. BTB, bone–patellar tendon–bone; F, female; LOE, level of evidence; M, male; NR, not reported; RTS, return to sport.
[b]Study compared BTB and hamstring tendon (HT) grafts.

TABLE 2
Demographic and RTS Data for Studies With HT Autografts[a]

First Author (Year)	LOE	Graft Type	No. of Athletes	Age a Surgery, y	M:F Sex, n	Follow-up, mo	RTS Rate, % (n)	Rate of Return to Preinjury Levels, % (n)	Rerupture Rate, % (n)
Shaieb[47] (2002)[b]	1	STG (4-strand)	37	30 (14-53)	21:16	24	91 (32/35)	63 (22/35)	5 (2/37)
Gobbi[17] (2003)	3	ST (4-strand plus bone block [Fastlok fixation])	80	28	52:28	36 (24-52)	NR	65 (52/80)	1 (1/80)
Feller[14] (2003)[b]	1	STG	34	26.3 ± 6	24:10	36	50 (17/34)	47 (16/34)	0 (0/34)
Lee[31] (2008)	4	STG (double-looped)	45	24.8 (18-40)	NR	60	NR	62 (28/45)	NR
Ardern[3] (2012)	3	STG (4-strand)	314	32.5 ± 10.2	183:131	39.6 ± 13.8	66 (208/314)	45 (140/314)	NR
Mascarenhas[35] (2012)[b]	3	STG (4-strand)	23	18 ± 3	10:13	48 ± 24	70 (16/23)	43 (10/23)	NR
Daruwalla[10] (2014)[b]	4	NR	15	NR	15:0	>12	93 (14/15)	NR	NR
Kyung[29] (2015)	4	ST (4-strand)	144	29 ± 11.3	144:0	26.9 ± 4.4	83 (120/144)	NR	NR
Sandon[43] (2015)[b]	3	NR	183	NR	NR	NR	52 (95/183)	NR	NR
Kautzner[26] (2015)[b]	1	NR	42	NR	0:42	24	90 (38/42)	62 (26/42)	0 (0/42)
Rodriguez-Roiz[40] (2015)	4	NR	99	30 (14-52)	74:25	36	91 (90/99)	52 (51/99)	NR
Liu[34] (2016)	1	STG (3- or 4-strand)	34	29.7 (17-47)	NR	80.8 (75-86)	68 (23/34)	9 (3/34)	0 (0/34)
Notarnicola[38] (2016)	5	STG	80	29.7 ± 8.4	74:6	13 ± 2	48 (38/80)	NR	NR
Sonnery-Cottet[48] (2017)[b]	2	STG (4-strand)	147	23.5 ± 4.0	NR	38.4 ± 8.5 (24-54)	NR	60 (88/147)	NR
Webster[52] (2017)	4	NR	140	17.2 ± 1.3	82:58	61.2 (36-84)	76 (107/140)	50 (70/140)	NR
Liptak[33] (2017)[b]	4	NR	39	NR	39:0	NR	77 (30/39)	54 (14/26)	NR
Gupta[19] (2018)[b]	3	STG	169	23.5 (16-46)	153:16	62.18 ± 25.9	79 (133/169)	33 (56/169)	4 (7/169)
Edwards[11] (2018)	3	NR	113	25.9 ± 7.1	75:38	12 (10-14)	64 (72/113)	NR	NR

[a]Data are presented as mean, mean ± SD, mean (range), or mean ± SD (range) unless otherwise specified. F, female; HT, hamstring tendon; LOE, level of evidence; M, male; NR, not reported; RTS, return to sport; ST, semitendinosus; STG, semitendinosus/gracilis.
[b]Study compared bone–patellar tendon–bone (BTB) and HT grafts.

When evaluating return to preinjury levels of sport, the pooled rate of return was 24.3% lower (48.9%) than the overall RTS rate (73.2%). However, the rate of return to preinjury levels was very similar between autograft groups (50.0% BTB vs 48.5% HT). Results of our subanalysis of return to preinjury levels in level 1 and 2 studies (57.1% BTB and 52.7% HT), while slightly higher than our pooled results, once again demonstrated a similar

TABLE 3
Pooled Demographic and RTS Data by Graft Type[a]

Graft	No. of Athletes	No. of Studies	Mean Age at Surgery, y	Mean Follow-up, mo	RTS Rate, % (n)	Rate of Return to Preinjury Levels, % (n)	Rerupture Rate, % (n)
BTB	610	11	25.0	36.6	81.0 (393/485)	50.0 (209/418)	2.2 (6/269)
HT	1738	18	23.1	39.4	70.6 (1033/1464)	48.5 (576/1188)	2.5 (10/396)
Overall	2348	20	23.6	38.7	73.1 (1426/1952)	48.9 (785/1606)	2.4 (16/665)

[a]BTB, bone–patellar tendon–bone; HT, hamstring tendon; RTS, return to sport.

TABLE 4
Risk-of-Bias Assessment for Observational Studies

First Author (Year)	Bias due to Confounding	Bias in Selection of Participants Into Study	Bias in Classification of Interventions	Bias due to Deviations From Intended Interventions	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result
Gobbi[16] (2002)	Serious	Moderate	Low	Low	Low	Moderate	Moderate
Gobbi[17] (2003)	Serious	Moderate	Low	Low	Low	Moderate	Moderate
Jennings[25] (2003)	Serious	Low	Low	Low	Low	Moderate	Moderate
Lee[31] (2008)	Serious	Serious	Low	Low	Low	Moderate	Moderate
Ardern[3] (2012)	Serious	Moderate	Low	Low	Serious	Moderate	Moderate
Mascarenhas[35] (2012)	Serious	Moderate	Low	Low	Low	Moderate	Moderate
Daruwalla[10] (2014)	Serious	Serious	Low	Low	Serious	Moderate	Serious
Kyung[29] (2015)	Serious	Serious	Low	Low	Serious	Moderate	Serious
Sandon[43] (2015)	Moderate	Moderate	Low	Low	Serious	Moderate	Serious
Rodriguez-Roiz[40] (2015)	Serious	Serious	Low	Low	Low	Moderate	Serious
Notarnicola[38] (2016)	Moderate	Low	Low	Low	Low	Moderate	Moderate
Sonnery-Cottet[48] (2017)	Low	Low	Low	Low	Low	Moderate	Moderate
Webster[52] (2017)	Serious	Serious	Low	Low	Serious	Moderate	Serious
Liptak[33] (2017)	Moderate	Low	Low	Low	Low	Moderate	Moderate
Gupta[19] (2018)	Moderate	Moderate	Low	Low	Low	Moderate	Serious
Edwards[11] (2018)	Moderate	Low	Low	Low	Low	Moderate	Moderate

pattern. Furthermore, we found the overall rerupture rate to be 2.4%, with relatively similar rates in the BTB group (2.2%) and the HT group (2.5%). To our knowledge, this is the first systematic review and meta-analysis directly comparing primary ACL reconstruction with BTB and HT autografts and sport-related outcomes (RTS and return to preinjury levels of play).

There remains a lack of consensus on which ACL graft choice will optimize RTS for athletes at the highest level of competition, with surgeon preference continuing to play a considerable role in graft selection.[24] It is generally accepted that autografts are the appropriate graft of choice for young (<25 years of age), high-demand athletes because the reported failure rates for allograft reconstruction in these patients is up to 3 times higher than for autograft reconstruction.[6] In a recent systematic review, Wasserstein et al[51] found that the pooled failure rate for allografts was 25% compared with the autograft failure rate of 9.6% in patients aged <25 years. However, when comparing autograft options, the current literature remains mixed in terms of reporting which autograft choice is optimal for competitive athletes to increase their RTS rate. As the 2 most common autograft options, BTB and HT grafts have been the topic of much debate with regard to which graft is superior, leading to numerous comparative studies.[26,27,29,35,42,45] While the subjective patient-reported outcomes for both BTB and HT autografts overall are thought to be similar, some authors have advocated for the use of BTB autografts for the documented better objective stability and lack of stretching that

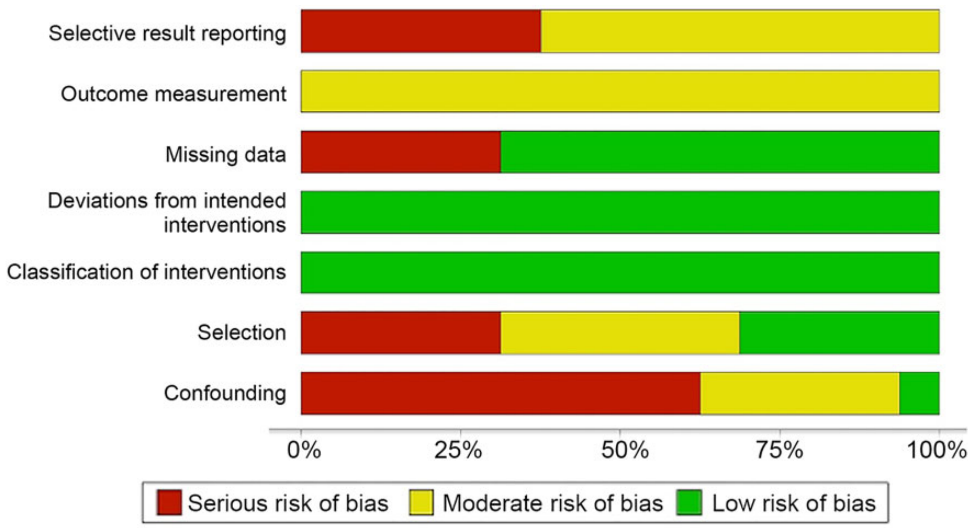

Figure 2. Risk of bias assessment for included studies, with green representing a low risk of bias for a given criteria, yellow indicating a moderate risk of bias, and red indicating a serious risk of bias.

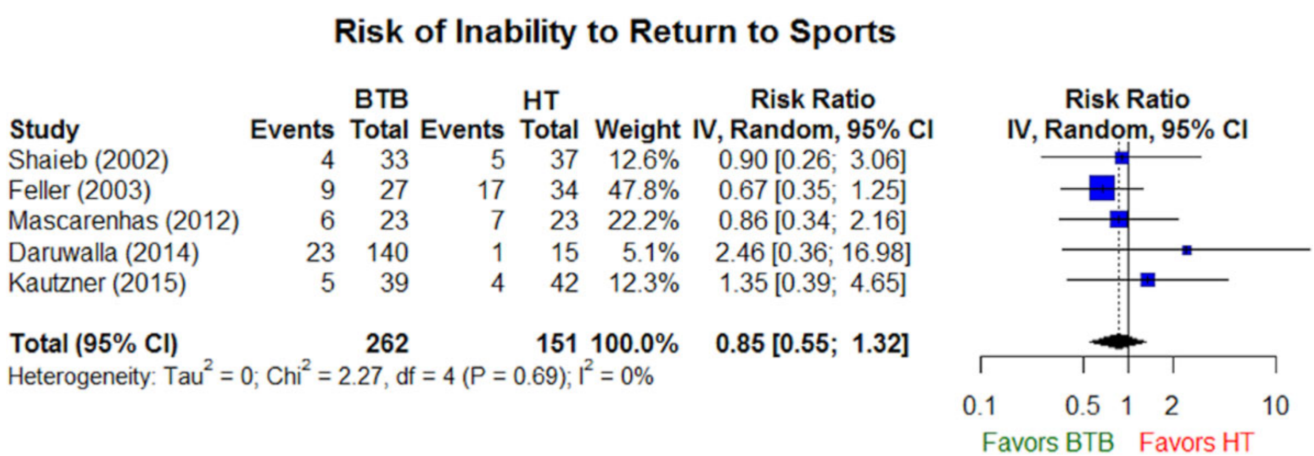

Figure 3. Assessment of risk of inability to return to sport with bone–patellar tendon–bone (BTB) grafts compared with hamstring tendon (HT) grafts. IV, inverse variance.

can be seen when compared with HT autografts.[27,45,55] Additional studies have shown that HT autografts are associated with prolonged hamstring weakness in knee flexion as well as sensory loss resulting from saphenous nerve damage.[8,20,28,41,55] Conversely, some surgeons avoid BTB autografts because of higher reported rates of persistent anterior knee pain and prefer HT autografts in an effort to reduce morbidity related to graft harvest.[20,41,55]

Our pooled rate of RTS was 73.2%, similar to reported rates of 81% to 83% in previous meta-analyses.[2,4,30] The slightly lower rate may be attributable to patient demographics or the type of sport reported within the studies that we reviewed. The meta-analysis by Lai et al[30] reported the highest rate of RTS, with 83% of patients returning after primary ACL reconstruction in a population of elite athletes who likely had access to a high level of medical care and intensive rehabilitation. These factors, along with superior levels of motivation, physical fitness, talent, resources, and financial incentive to return to elite play, may contribute to the higher rates of return to preinjury levels noted in this study of professional athletes.[33] Another study by Ardern et al[2] reported higher rates of return to play in a nonelite patient population. However, their results may be confounded by heterogeneity in the sporting demographics. Rodriguez-Roiz et al[40] found that patients who participated in sports that required more cutting and pivoting were less likely to return to preinjury levels of play. A number of the studies included in the current review prominently featured athletes in sports with a high degree of cutting, pivoting, and contact such as rugby, soccer, football, and basketball, although incomplete reporting of such data in some studies made precise quantification

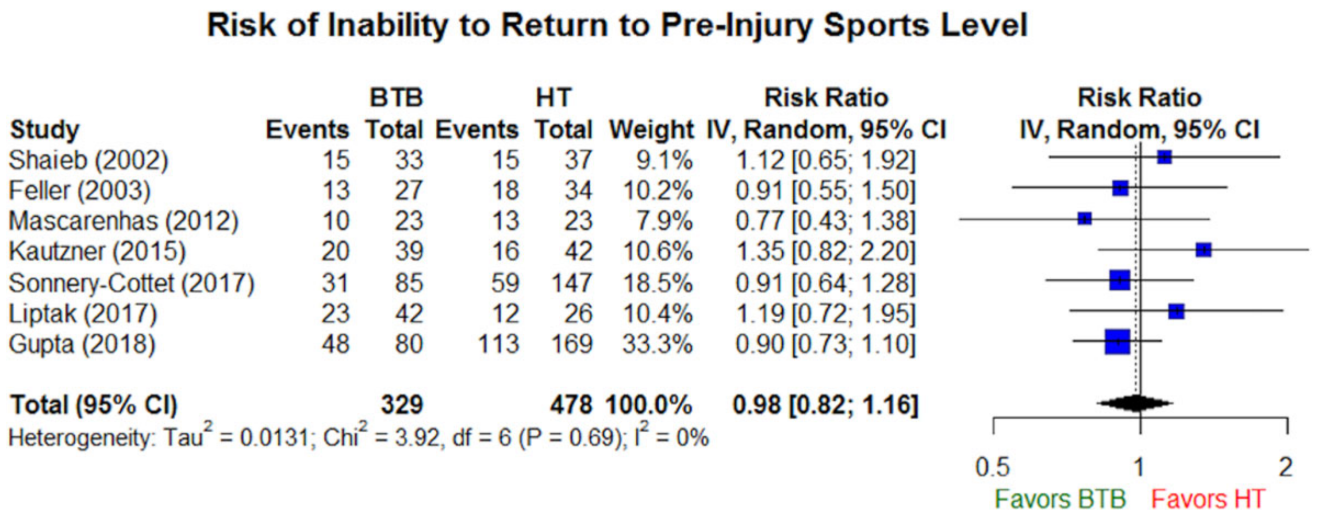

Figure 4. Assessment of risk of inability to return to preinjury levels with bone–patellar tendon–bone (BTB) grafts compared with hamstring tendon (HT) grafts. IV, inverse variance.

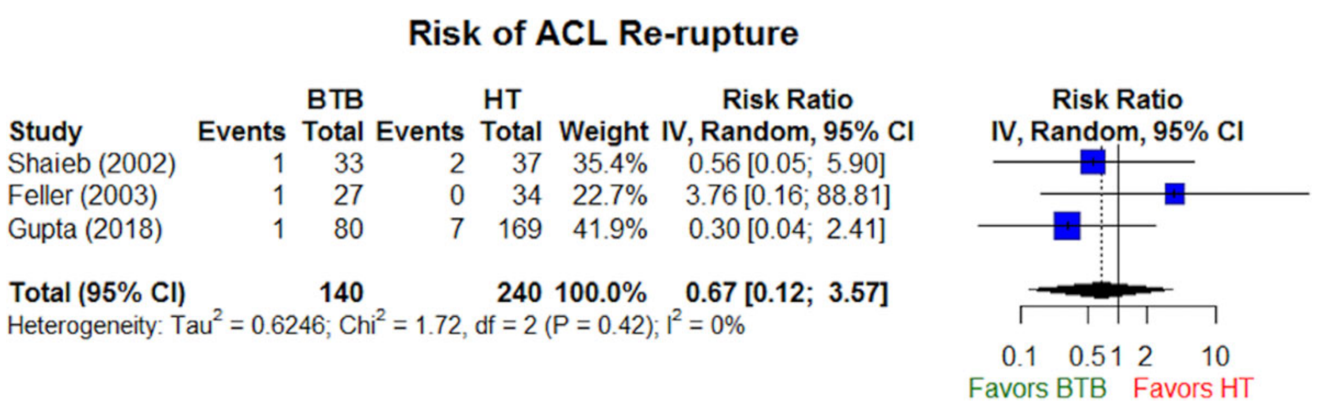

Figure 5. Assessment of risk of reruptures with bone–patellar tendon–bone (BTB) grafts compared with hamstring tendon (HT) grafts. ACL, anterior cruciate ligament; IV, inverse variance.

difficult. Further support for this explanation comes from a recent systematic review by Mohtadi and Chan[37] that found that only 63% of National Football League players returned after ACL reconstruction, while up to 97% of National Hockey League players returned after the same injuries.

While our systematic review demonstrated an overall RTS rate among athletes with BTB autografts (81.0%) that is in line with the existing literature, the RTS rate for patients with HT autografts (70.6%) was found to be lower than previously reported. Furthermore, the range of reported RTS rates was more precise for the BTB group than the HT group (69%-94% vs 48%-93%, respectively). BTB autografts have historically been considered to have lower revision rates and higher postoperative stability in comparison with HT autografts and may be preferable in competitive high-level athletes requiring pivot shift of the knee in contact sports.[7,13,48] For this reason, the patients with BTB autografts in our review may be representative of a more athletic population than those receiving HT autografts and therefore are more likely to return to sport because of financial reasons, motivation, ability, and scholarship. In contrast, Ardern et al[2] reported an RTS rate of 83% for BTB autografts compared with 89% for HT autografts; however, their review did not stratify the level of sport or type of sport played when reporting on RTS by graft type. It is difficult to determine whether this or other factors played a role in the observed discrepancy between our findings and those of others.

It is important to separate RTS from return to preinjury levels of sport when discussing the outcomes of athletes. For example, in professional athletes, it is not uncommon that athletes return to the professional level but not to preinjury levels.[37] Similarly to the pooled RTS data, the overall rate of return to preinjury levels of sport (48.9%) for both BTB and HT autografts in our systematic review was lower than that in recent meta-analyses by Ardern et al,[2,4] which reported a range of 63% to 65% returning to preinjury levels. A meta-analysis by Xie et al[55] reported a 55.6% rate of return to preinjury activity levels over 8 studies and 507 patients. Gabler et al[15] found a pooled rate of return to preinjury activity levels of 71.7% over 5 studies, although 4 of these examined HT autografts only. It is possible that our lower rates of return to preinjury levels can be explained by our stricter inclusion criteria regarding athletic-specific populations. Previous studies may have included more nonathletic general patient populations that require a lesser degree of functional capacity to return to preinjury activity levels.

Rates of return to preinjury levels of play were similar between the 2 autograft groups (50.0% BTB vs 48.5% HT) in our review of the literature, but the range of rates of return to preinjury levels was smaller for the BTB group (32%-64% BTB vs 9%-68% HT). This is interesting given the RTS data, as one might expect BTB grafts to follow the same trend and have a higher rate of return to preinjury sporting levels. One possible explanation is that, while patients with BTB grafts returned to sport at a higher rate because of the potential bias toward using BTB grafts in athletes with higher demands, once patients return to sport, the grafts are about equally as effective in allowing patients to return to their preinjury level. There are many other factors involved in return to preinjury sport levels, including psychological factors and confidence in the reconstructed knee as well as the motivation of the athlete and intensity of the postoperative rehabilitation protocol.[53] Similar to our findings, Lindanger et al[32] reported the long-term outcomes (25-year follow-up) of returning to pivot sports after primary ACL reconstruction with BTB autografts and found that 83% of the athletes were able to return to sport, but only 53% returned to preinjury levels. Additionally, the incidence of contralateral ACL injuries was 28% among the athletes who returned to sport versus 4% among the athletes who did not return. The authors concluded that “ACL reconstruction does not necessarily enable an athlete a return to preinjury sports participation.” Webster et al[53] reported that only 61% (135/222) of patients were able to return to their preinjury levels of performance, with similar rates between male and female patients. In the patients who returned to preinjury sports, the authors found that higher psychological readiness, greater limb symmetry, higher subjective knee scores, and a higher activity level were all associated with returning to sport at the preinjury level. Our systematic review found that regardless of the graft type, less than half of the athletes ever returned to sport at the preinjury level after primary ACL reconstruction. There are many other factors that play into successful RTS, especially returning to the preinjury level. This information is important to know and useful when counseling athletes regarding postoperative expectations and RTS.

There is also disagreement in the available literature regarding return to preinjury levels between BTB and HT autografts. Ardern et al[2] reported that a lower proportion of patients returned to their preinjury competitive level of sport within the BTB group (27% BTB vs 47% HT), while Xie et al[55] found that BTB autografts performed significantly better, with 60.5% of patients returning to preinjury activity levels compared with 51.1% with HT autografts. Despite similar functional outcomes for both graft types, Xie et al suggested that BTB autografts be used in young and high-demand athletes to enable a greater proportion of patients to return to their preinjury sport postoperatively with higher levels of activity. The difference in the RTS rates between BTB and HT autografts as reported in these studies is likely a result of the heterogeneity in the patient population, type of sport, difference in demographics, and time of follow-up, among other factors.

The pooled rate of graft reruptures overall was 2.4% in our systematic review. This is within the range of previous studies, with pooled rerupture rates ranging from 2.8% to 6.4%.[39,42,44,54,55] There was a similar rerupture rate with BTB autografts (2.2%) when compared with HT autografts (2.5%) in our review. However, it is important to note that a large percentage of articles included in this review did not report on rerupture rates. Because we found that there was a lower RTS rate in the HT group, it is possible that the rerupture rate was higher than reported in the HT group compared with the BTB group, but it was not reported in the original study. In a level 2 cohort study by Persson et al[39] that reported an overall rerupture rate of 4.2%, there was a significantly higher rerupture rate with HT grafts (4%) compared with BTB grafts (2%). The decreased rerupture rate with BTB autografts could be explained by both the increased objective stability of this graft and the trend toward the use of BTB grafts in higher level athletes, who may benefit from more rigorous physical therapy and rehabilitation protocols. It is important to note that in our systematic review, the mean age of patients in the HT group was 2 years younger than that in the BTB group. As younger age is also a predictor of higher graft failure rates, this may have biased our results and may explain the higher rate of subsequent ACL injuries noted in the HT group compared with the BTB group.[23,44] Our meta-analysis suggested similar rates of RTS, return to preinjury levels of play, and reruptures between the 2 autograft groups. Xie et al,[55] in a meta-analysis of outcomes after ACL reconstruction with BTB versus HT autografts, also reported similar rerupture rates between BTB and HT autografts and objective International Knee Documentation Committee scores; however, the BTB group had better rotational stability and returned to higher levels of activity compared with the HT group. Additionally, Samuelsen et al[42] in their meta-analysis reported no significant difference in rerupture rates and instrumented laxity between BTB and HT grafts (2.8% and 2.84%, respectively).

There are limitations to consider when interpreting the results of our systematic review. The majority of the articles in this review were extracted from level 3 and 4 evidence, representing a paucity of high-quality data available, and indicate a call for higher level studies on this topic. We used the ROBINS-I tool to assess bias in these instances to evaluate these studies explicitly.[50] This tool was felt to be most appropriate to our systematic review, as it is applicable to both randomized and nonrandomized trials and offers many well-delineated criteria, each composed of discrete subcriteria on which to judge bias. This level of detail in evaluating studies and the use of categorical risk classifications are important in light of the inclusion of lower level studies. Other methodological quality assessments were deemed less appropriate, as they would have been less able to distinguish between the studies; these include the Jadad score, which weights blinding greatly and has few additional distinguishing criteria, or the Coleman score, which does not offer categorical risk classifications and relies heavily on outcome and rehabilitation criteria that are widely variable within this topic and would therefore be improper to compare across the included studies.

As most studies involved were retrospective in nature, there was a high risk of selection bias seen in these studies focusing on an athletic population. Furthermore, there was heterogeneity in terms of patient age, sex ratio, level of competition, and follow-up time, all of which can have an impact on reported rates of RTS and return to preinjury levels. Another challenge was that physical therapy protocols change from institution to institution and also change over time; therefore, studies that are more than 10 years old may have outdated rehabilitation protocols that could affect RTS rates. Also, given that most of these data were acquired via patient-reported outcomes, the shortcomings in standardization were problematic for the acquisition of unbiased and uniform data. Additional studies would benefit greatly from the use of standardized self-assessment scoring systems designed for reporting RTS data in patient-athletes.

As with any systematic review assessing RTS, there was a lack of consistency in the definitions of subjective outcomes, particularly RTS and return to preinjury levels among patient-athletes. In a previous study by our group, we noted that the reporting of RTS and return to preinjury level suffers from the lack of a clear consensus definition as to what these terms specifically mean to athletes.[1] RTS could refer to patient-athletes returning to organized team activities, full-speed practice, full competition for some period of time, or an entire season of competition. Within our study, we used our own judgment in reporting RTS rates for the study by Ardern et al,[3] which reported on patients who "attempted" to return to sport or patients who returned to sport at final follow-up. In a similar manner, Jennings et al[25] reported on both patients who had returned to sport at some time during follow-up as well as those who were playing their sport at final follow-up. It was our interpretation that only the data from the final time point from the Ardern et al[3] study should be included for analysis, as "attempted" did not constitute true RTS. For the Jennings et al study, we reported the percentage of patients who returned to sport at some time over the follow-up period rather than only at final follow-up. This decision was made because there are numerous graft-independent reasons to not participate in a sport at final follow-up, but if the patient returned at some point, that would be more indicative of graft success. Distinctions such as these require discretion when collecting data for a systematic review, so as to report appropriate and clinically relevant numbers.

CONCLUSION

This systematic review and meta-analysis evaluated and synthesized RTS and return to preinjury sport levels after primary ACL reconstruction using a BTB or HT autograft exclusively in athletes participating in sports from a recreational to professional level. Our study found that BTB autografts yielded a higher overall RTS rate compared with HT autografts (81.0% vs 70.6%, respectively), while the rates of return to preinjury levels were similar between the 2 groups (50.0% vs 48.5%, respectively), as were the rerupture rates (2.2% vs 2.5%, respectively). While our RTS rate for BTB autografts in athletes was similar to rates found in previous meta-analyses that were not explicitly exclusive of nonathletes, the RTS rate with HT grafts in this study was lower than what has been reported previously. We also found a lower rate of return to preinjury levels for both BTB and HT autografts compared with the literature. Our findings suggest that BTB autografts may be optimal for ACL reconstruction in high-demand athletes to improve overall RTS rates. However, among those athletes who did return to sport, the rate of return to preinjury activity levels was very similar between both graft options. What is interesting is that regardless of the graft type, less than half of the athletes ever returned to sport at the preinjury level after primary ACL reconstruction. Additional high-quality randomized trials are warranted in this field, with increased attention paid to stratification by competition level, sport played, and return performance as well as enhanced efforts toward clarity in defining RTS and return to preinjury activity levels to definitively establish the equivalence or nonequivalence of these 2 autograft types in athletes.

REFERENCES

1. Abdul-Rassoul H, Galvin JW, Curry EJ, Simon J, Li X. Return to sport after surgical treatment for anterior shoulder instability: a systematic review. Response. *Am J Sports Med*. 2019;47(3):NP24-NP27.
2. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. 2014;48(21):1543-1552.
3. Ardern CL, Taylor NF, Feller JA, Webster KE. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2012;40(1):41-48.
4. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med*. 2011;45(7):596-606.
5. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med*. 2011;39(3):538-543.
6. Bottoni CR, Smith EL, Shaha J, et al. Autograft versus allograft anterior cruciate ligament reconstruction: a prospective, randomized clinical study with a minimum 10-year follow-up. *Am J Sports Med*. 2015;43(10):2501-2509.

7. Bradley JP, Klimkiewicz JJ, Rytel MJ, Powell JW. Anterior cruciate ligament injuries in the National Football League: epidemiology and current treatment trends among team physicians. *Arthroscopy*. 2002;18(5):502-509.
8. Burks RT, Crim J, Fink BP, Boylan DN, Greis PE. The effects of semitendinosus and gracilis harvest in anterior cruciate ligament reconstruction. *Arthroscopy*. 2005;21(10):1177-1185.
9. Ciccotti MC, Secrist E, Tjoumakaris F, Ciccotti MG, Freedman KB. Anatomic anterior cruciate ligament reconstruction via independent tunnel drilling: a systematic review of randomized controlled trials comparing patellar tendon and hamstring autografts. *Arthroscopy*. 2017;33(5):1062-1071.
10. Daruwalla JH, Greis PE, Hancock R; Group ASPC, Xerogeanes JW. Rates and determinants of return to play after anterior cruciate ligament reconstruction in NCAA Division 1 college football athletes: a study of the ACC, *SEC, and PAC-12 Conferences*. *Orthop J Sports Med*. 2014;2(8):2325967114543901.
11. Edwards PK, Ebert JR, Joss B, et al. Patient characteristics and predictors of return to sport at 12 months after anterior cruciate ligament reconstruction: the importance of patient age and postoperative rehabilitation. *Orthop J Sports Med*. 2018;6(9):2325967118797575.
12. Ejerhed L, Kartus J, Sernert N, Köhler K, Karlsson J. Patellar tendon or semitendinosus tendon autografts for anterior cruciate ligament reconstruction? A prospective randomized study with a two-year follow-up. *Am J Sports Med*. 2003;31(1):19-25.
13. Erickson BJ, Harris JD, Heninger JR, et al. Performance and return-to-sport after ACL reconstruction in NFL quarterbacks. *Orthopedics*. 2014;37(8):e728-e734.
14. Feller JA, Webster KE. A randomized comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports Med*. 2003;31(4):564-573.
15. Gabler CM, Jacobs CA, Howard JS, Mattacola CG, Johnson DL. Comparison of graft failure rate between autografts placed via an anatomic anterior cruciate ligament reconstruction technique: a systematic review, meta-analysis, and meta-regression. *Am J Sports Med*. 2016;44(4):1069-1079.
16. Gobbi A, Diara A, Mahajan S, Zanazzo M, Tuy B. Patellar tendon anterior cruciate ligament reconstruction with conical press-fit femoral fixation: 5-year results in athletes population. *Knee Surg Sports Traumatol Arthrosc*. 2002;10(2):73-79.
17. Gobbi A, Tuy B, Mahajan S, Panuncialman I. Quadrupled bone-semitendinosus anterior cruciate ligament reconstruction: a clinical investigation in a group of athletes. *Arthroscopy*. 2003;19(7):691-699.
18. Gobbi A, Whyte GP. Long-term outcomes of primary repair of the anterior cruciate ligament combined with biologic healing augmentation to treat incomplete tears. *Am J Sports Med*. 2018;46(14):3368-3377.
19. Gupta R, Sood M, Malhotra A, et al. Low re-rupture rate with BPTB autograft and semitendinosus gracilis autograft with preserved insertions in ACL reconstruction surgery in sports persons. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(8):2381-2388.
20. Hardy A, Casabianca L, Andrieu K, Baverel L, Noailles T; Junior French Arthroscopy Society. Complications following harvesting of patellar tendon or hamstring tendon grafts for anterior cruciate ligament reconstruction: systematic review of literature. *Orthop Traumatol Surg Res*. 2017;103(8_suppl):S245-S248.
21. Harris JD, Abrams GD, Bach BR, et al. Return to sport after ACL reconstruction. *Orthopedics*. 2014;37(2):e103-e108.
22. Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Trends in incidence of ACL reconstruction and concomitant procedures among commercially insured individuals in the United States, 2002-2014. *Sports Health*. 2018;10(6):523-531.
23. Hettrich CM, Dunn WR, Reinke EK, Group M, Spindler KP. The rate of subsequent surgery and predictors after anterior cruciate ligament reconstruction: two- and 6-year follow-up results from a multicenter cohort. *Am J Sports Med*. 2013;41(7):1534-1540.
24. Houck DA, Kraeutler MJ, Vidal AF, et al. Variance in anterior cruciate ligament reconstruction graft selection based on patient demographics and location within the Multicenter Orthopaedic Outcomes Network cohort. *J Knee Surg*. 2018;31(5):472-478.
25. Jennings S, Rasquinha V, Dowd GSE. Medium term follow up of endoscopically assisted BPTB ACL reconstruction using a two-incision technique: return to sporting activity. *Knee*. 2003;10(4):329-333.
26. Kautzner J, Kos P, Hanus M, Trc T, Havlas V. A comparison of ACL reconstruction using patellar tendon versus hamstring autograft in female patients: a prospective randomised study. *Int Orthop*. 2015;39(1):125-130.
27. Kim SJ, Choi CH, Kim SH, et al. Bone-patellar tendon-bone autograft could be recommended as a superior graft to hamstring autograft for ACL reconstruction in patients with generalized joint laxity: 2- and 5-year follow-up study. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(9):2568-2579.
28. Konrath JM, Vertullo CJ, Kennedy BA, Bush HS, Barrett RS, Lloyd DG. Morphologic characteristics and strength of the hamstring muscles remain altered at 2 years after use of a hamstring tendon graft in anterior cruciate ligament reconstruction. *Am J Sports Med*. 2016;44(10):2589-2598.
29. Kyung H-S, Lee H-J, Oh C-W, Hong H-P. Comparison of results after anterior cruciate ligament reconstruction using a four-strand single semitendinosus or a semitendinosus and gracilis tendon. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(11):3238-3243.
30. Lai CCH, Ardern CL, Feller JA, Webster KE. Eighty-three per cent of elite athletes return to preinjury sport after anterior cruciate ligament reconstruction: a systematic review with meta-analysis of return to sport rates, graft rupture rates and performance outcomes. *Br J Sports Med*. 2018;52(2):128-138.
31. Lee DYH, Karim SA, Chang HC. Return to sports after anterior cruciate ligament reconstruction: a review of patients with minimum 5-year follow-up. *Ann Acad Med Singap*. 2008;37(4):273-278.
32. Lindanger L, Strand T, Molster AO, Solheim E, Inderhaug E. Return to play and long-term participation in pivoting sports after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2019;47(14):3339-3346.
33. Liptak MG, Angel KR. Return to play and player performance after anterior cruciate ligament injury in elite Australian rules football players. *Orthop J Sports Med*. 2017;5(6):2325967117711885.
34. Liu Y, Cui G, Yan H, Yang Y, Ao Y. Comparison between single- and double-bundle anterior cruciate ligament reconstruction with 6- to 8-stranded hamstring autograft: a prospective, randomized clinical trial. *Am J Sports Med*. 2016;44(9):2314-2322.
35. Mascarenhas R, Tranovich MJ, Kropf EJ, Fu FH, Harner CD. Bone-patellar tendon-bone autograft versus hamstring autograft anterior cruciate ligament reconstruction in the young athlete: a retrospective matched analysis with 2-10 year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(8):1520-1527.
36. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097.
37. Mohtadi NG, Chan DS. Return to sport-specific performance after primary anterior cruciate ligament reconstruction: a systematic review. *Am J Sports Med*. 2018;46(13):3307-3316.
38. Notarnicola A, Maccagnano G, Barletta F, et al. Returning to sport after anterior cruciate ligament reconstruction in amateur sports men: a retrospective study. *Muscles Ligaments Tendons J*. 2016;6(4):486-491.
39. Persson A, Fjeldsgaard K, Gjertsen JE, et al. Increased risk of revision with hamstring tendon grafts compared with patellar tendon grafts after anterior cruciate ligament reconstruction: a study of 12,643 patients from the Norwegian Cruciate Ligament Registry, 2004-2012. *Am J Sports Med*. 2014;42(2):285-291.
40. Rodriguez-Roiz JM, Caballero M, Ares O, Sastre S, Lozano L, Popescu D. Return to recreational sports activity after anterior cruciate ligament reconstruction: a one- to six-year follow-up study. *Arch Orthop Trauma Surg*. 2015;135(8):1117-1122.
41. Sadeghpour A, Ebrahimpour A, Attar B, Azizian Z. Comparison of patellar versus hamstring tendon autografts in arthroscopic anterior

cruciate ligament reconstruction: a 6-month follow-up of a randomized clinical trial. *J Res Med Sci*. 2017;22:105.
42. Samuelsen BT, Webster KE, Johnson NR, Hewett TE, Krych AJ. Hamstring autograft versus patellar tendon autograft for ACL reconstruction: is there a difference in graft failure rate? A meta-analysis of 47,613 patients. *Clin Orthop Relat Res*. 2017;475(10):2459-2468.
43. Sandon A, Werner S, Forssblad M. Factors associated with returning to football after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(9):2514-2521.
44. Schlumberger M, Schuster P, Schulz M, et al. Traumatic graft rupture after primary and revision anterior cruciate ligament reconstruction: retrospective analysis of incidence and risk factors in 2915 cases. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(5):1535-1541.
45. Schuette HB, Kraeutler MJ, Houck DA, McCarty EC. Bone-patellar tendon-bone versus hamstring tendon autografts for primary anterior cruciate ligament reconstruction: a systematic review of overlapping meta-analyses. *Orthop J Sports Med*. 2017;5(11):2325967117736484.
46. Shaerf DA, Pastides PS, Sarraf KM, Willis-Owen CA. Anterior cruciate ligament reconstruction best practice: a review of graft choice. *World J Orthop*. 2014;5(1):23-29.
47. Shaieb MD, Kan DM, Chang SK, Marumoto JM, Richardson AB. A prospective randomized comparison of patellar tendon versus semitendinosus and gracilis tendon autografts for anterior cruciate ligament reconstruction. *Am J Sports Med*. 2002;30(2):214-220.
48. Sonnery-Cottet B, Saithna A, Cavalier M, et al. Anterolateral ligament reconstruction is associated with significantly reduced ACL graft rupture rates at a minimum follow-up of 2 years: a prospective comparative study of 502 patients from the SANTI Study Group. *Am J Sports Med*. 2017;45(7):1547-1557.
49. Stanczak K, Zielinska M, Synder M, Domzalski M, Polguj M, Sibinski M. Comparison of hamstring and patellar tendon grafts in anterior cruciate ligament reconstruction: a prospective randomized study. *J Int Med Res*. 2018;46(2):785-791.
50. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:i4919.
51. Wasserstein D, Sheth U, Cabrera A, Spindler KP. A systematic review of failed anterior cruciate ligament reconstruction with autograft compared with allograft in young patients. *Sports Health*. 2015;7(3):207-216.
52. Webster KE, Feller JA, Whitehead TS, Myer GD, Merory PB. Return to sport in the younger patient with anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2017;5(4):2325967117703399.
53. Webster KE, McPherson AL, Hewett TE, Feller JA. Factors associated with a return to preinjury level of sport performance after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2019;47(11):2557-2562.
54. Wright RW, Magnussen RA, Dunn WR, Spindler KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: a systematic review. *J Bone Joint Surg Am*. 2011;93(12):1159-1165.
55. Xie X, Liu X, Chen Z, Yu Y, Peng S, Li Q. A meta-analysis of bone–patellar tendon–bone autograft versus four-strand hamstring tendon autograft for anterior cruciate ligament reconstruction. *Knee*. 2015;22(2):100-110.

APPENDIX

TABLE A1
Sports Played, Level of Athletics, Concomitant Procedures, and Revision Surgery for Studies With BTB Autografts[a]

First Author (Year)	
Gobbi[16] (2002)	
Sports played	Downhill skiing (n = 8), motocross (n = 6), basketball (n = 6), soccer (n = 6), tennis (n = 4), volleyball (n = 4), mountain biking (n = 3), handball (n = 1), alpinism (n = 1), horseback riding (n = 1)
Level of athletics	Competitive (n = 35), recreational (n = 5)
Concomitant procedures	None
Revision surgery	Cyclops lesion excision (n = 2), lateral patellar chondropathy (n = 1), medial meniscectomy (n = 1), tibial bone block repositioning with interference screw (n = 1)
Shaieb[47] (2002)[b]	
Sports played	Soccer (n = 3), skiing (n = 6), basketball (n = 4), baseball (n = 2), football (n = 3), volleyball (n = 3), softball (n = 1), martial arts (n = 2), work (n = 4), other (n = 3)
Level of athletics	Mixed
Concomitant procedures	Medial meniscectomy (n = 8), lateral meniscectomy (n = 7), bilateral meniscectomy (n = 2)
Revision surgery	Manipulation under anesthesia (n = 1), tibial interference screw removal for infection (n = 1), revision ACL reconstruction (n = 1)
Feller[14] (2003)[b]	
Sports played	Most commonly Australian rules football and basketball; work (n = 2)
Level of athletics	NR
Concomitant procedures	Partial medial meniscectomy (n = 6), medial meniscal repair (n = 5), partial lateral meniscectomy (n = 6), lateral meniscal repair (n = 1)
Revision surgery	Revision ACL reconstruction (n = 1), debridement for infection (n = 1), debridement for notch impingement (n = 2), partial medial meniscectomy (n = 1), diagnostic arthroscopic surgery (n = 2)
Jennings[25] (2003)	
Sports played	NR
Level of athletics	NR
Concomitant procedures	Medial meniscal excision (n = 15), lateral meniscal excision (n = 2)
Revision surgery	Medial meniscal excision (n = 1), tibial staple removal (n = 5), cyclops lesion excision (n = 1)

(continued)

Table A1 (continued)

First Author (Year)	
Mascarenhas[35] (2012)[b]	
Sports played	Basketball (n = 10), football (n = 3), soccer (n = 3), skiing (n = 2), dancing/gymnastics (n = 3), martial arts (n = 1), wrestling (n = 1)
Level of athletics	Mixed
Concomitant procedures	Meniscal repair (n = 3), meniscectomy (n = 5)
Revision surgery	Arthroscopic knee debridement (n = 1)
Daruwalla[10] (2014)[b]	
Sports played	Football
Level of athletics	NCAA Division I
Concomitant procedures	NR
Revision surgery	NR
Kautzner[26] (2015)[b]	
Sports played	NR
Level of athletics	Professional (n = 4), amateur (n = 35)
Concomitant procedures	NR
Revision surgery	Cyclops lesion excision for revision (n = 1), diagnostic arthroscopic surgery for persistent instability (n = 3)
Sandon[43] (2015)[b]	
Sports played	Soccer
Level of athletics	NR
Concomitant procedures	NR
Revision surgery	NR
Sonnery-Cottet[48] (2017)[b]	
Sports played	NR
Level of athletics	NR
Concomitant procedures	Medial meniscectomy (n = 5), medial suture (n = 46), lateral meniscectomy (n = 6), lateral suture (n = 24)
Revision surgery	Meniscectomy (n = 4), cyclops lesion excision (n = 5)
Liptak[33] (2017)[b]	
Sports played	Australian rules football
Level of athletics	Elite
Concomitant procedures	NR
Revision surgery	NR
Gupta[19] (2018)[b]	
Sports played	Mixed
Level of athletics	NR
Concomitant procedures	NR
Revision surgery	NR

[a]ACL, anterior cruciate ligament; BTB, bone–patellar tendon–bone; NCAA, National Collegiate Athletic Association; NR, not reported.
[b]Study compared BTB and hamstring tendon (HT) grafts.

TABLE A2
Sports Played, Level of Athletics, Concomitant Procedures, and Revision Surgery for Studies With HT Autografts[a]

First Author (Year)	
Shaieb[47] (2002)[b]	
Sports played	Soccer (n = 2), skiing (n = 3), basketball (n = 11), baseball (n = 2), football (n = 3), volleyball (n = 5), softball (n = 2), work (n = 2), motor vehicle (n = 3), other (n = 2)
Level of athletics	Mixed
Concomitant procedures	Medial meniscectomy (n = 7), lateral meniscectomy (n = 5), medial and lateral meniscectomy (n = 2), lateral meniscal repair (n = 4)
Revision surgery	Revision ACL reconstruction (n = 2)
Gobbi[17] (2003)	
Sports played	Soccer (n = 18), downhill skiing (n = 21), motocross (n = 11), basketball (n = 9), volleyball (n = 9), tennis (n = 4), mountain biking (n = 2), handball (n = 2), alpinism (n = 2), horseback riding (n = 2)
Level of athletics	Mixed
Concomitant procedures	NR
Revision surgery	Diagnostic arthroscopic surgery for partial graft rupture (n = 1), partial medial meniscectomy (n = 1), removal of Fastlok device (n = 7), arthroscopic lavage and debridement for deep infection (n = 1)
Feller[14] (2003)[b]	
Sports played	Most commonly Australian rules football and basketball
Level of athletics	NR
Concomitant procedures	Partial medial meniscectomy (n = 4), medial meniscal repair (n = 4), partial lateral meniscectomy (n = 6)
Revision surgery	Removal of prominent fixation post (n = 1), medial meniscectomy (n = 1), manipulation under anesthesia for lack of extension (n = 1)
Lee[31] (2008)	
Sports played	NR
Level of athletics	National (n = 2), recreational (n = 43), competitive (n = 21)
Concomitant procedures	NR
Revision surgery	NR
Ardern[3] (2012)	
Sports played	Australian football (n = 82), netball (n = 67), basketball (n = 44), soccer (n = 38), other (n = 83)
Level of athletics	Competitive sport before injury (n = 198), recreational (n = 56), social competitions (n = 38), training (n = 22)
Concomitant procedures	NR
Revision surgery	NR
Mascarenhas[35] (2012)[b]	
Sports played	Basketball (n = 10), football (n = 4), soccer (n = 4), skiing (n = 2), dancing/gymnastics (n = 1), softball (n = 1), lacrosse (n = 1)
Level of athletics	Mixed
Concomitant procedures	Meniscectomy (n = 3), meniscal repair (n = 5)
Revision surgery	Knee arthroscopic surgery (n = 1)
Daruwalla[10] (2014)[b]	
Sports played	Football
Level of athletics	NCAA Division I
Concomitant procedures	NR
Revision surgery	NR
Kyung[29] (2015)	
Sports played	Mostly soccer
Level of athletics	NR
Concomitant procedures	Meniscectomy (n = 28), meniscal repair (n = 20)
Revision surgery	Debridement for deep knee joint infection (n = 1) and superficial tibial infection (n = 3)
Sandon[43] (2015)[b]	
Sports played	Soccer
Level of athletics	NR
Concomitant procedures	NR
Revision surgery	NR
Kautzner[26] (2015)[b]	
Sports played	NR
Level of athletics	Professional (n = 6), amateur (n = 36)
Concomitant procedures	NR
Revision surgery	NR
Rodriguez-Roiz[40] (2015)	
Sports played	Football (n = 53), basketball/handball/volleyball (n = 12), tennis/paddle tennis (n = 5), skiing/snowboarding (n = 8), gymnasium activities/cycling (n = 21)

(continued)

Table A2 (continued)

First Author (Year)	
Level of athletics	Recreational
Concomitant procedures	Meniscectomy (n = 32), meniscal repair (n = 20), microfracture (n = 6)
Revision surgery	NR
Liu[34] (2016)	
Sports played	Basketball (n = 16), running (n = 14), soccer (n = 12), badminton/table tennis (n = 9)
Level of athletics	NR
Concomitant procedures	Lateral meniscectomy (n = 13), lateral meniscal repair (n = 12), medial meniscectomy (n = 19), medial meniscal repair (n = 4)
Revision surgery	NR
Notarnicola[38] (2016)	
Sports played	Jogging (n = 2), cycling (n = 2), volleyball (n = 3), tennis (n = 3), basketball (n = 2), soccer (n = 54), running (n = 4), athletics (n = 10)
Level of athletics	Amateur
Concomitant procedures	None
Revision surgery	NR
Sonnery-Cottet[48] (2017)[b]	
Sports played	NR
Level of athletics	Professional (n = 6), mixed
Concomitant procedures	Medial meniscectomy (n = 5), medial meniscal repair (n = 48), lateral meniscectomy (n = 7), lateral meniscal repair (n = 35)
Revision surgery	Meniscectomy (n = 7)
Webster[52] (2017)	
Sports played	Australian rules football, netball, soccer, basketball
Level of athletics	NR
Concomitant procedures	NR
Revision surgery	NR
Liptak[33] (2017)[b]	
Sports played	Australian rules football
Level of athletics	Elite
Concomitant procedures	NR
Revision surgery	NR
Gupta[19] (2018)[b]	
Sports played	Mixed
Level of athletics	NR
Concomitant procedures	NR
Revision surgery	NR
Edwards[11] (2018)	
Sports played	Australian football (n = 25), soccer (n = 20), netball (n = 17), basketball (n = 15), other (n = 36)
Level of athletics	Level I/II sports
Concomitant procedures	Meniscectomy (n = 47), meniscal repair (n = 4)
Revision surgery	NR

[a]ACL, anterior cruciate ligament; HT, hamstring tendon; NCAA, National Collegiate Athletic Association; NR, not reported.
[b]Study compared bone–patellar tendon–bone (BTB) and HT grafts.