Clinical Sports Medicine Update

Lower ACLR Failure Rates in Bone–Soft Tissue Versus Soft Tissue–Only Allografts in Adults

A Systematic Review and Meta-analysis

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Background: While allografts are commonly used for anterior cruciate ligament reconstruction (ACLR), evidence to guide specific allograft selection is lacking.

Purpose: To compare clinical and graft failure rates after ACLR using soft tissue–only allografts and bone–soft tissue allografts in adults.

Study Design: Systematic review and meta-analysis; Level of evidence, 4.

Methods: English-language studies with clinical outcome data on primary and revision ACLR in adults with nonirradiated soft tissue–only and bone–soft tissue grafts were identified in the search. Data extracted included allograft type, patient characteristics, follow-up time, and failure rates. The cumulative failure rate was defined as International Knee Documentation Committee grade C/D, graft retear, grade ≥2+ Lachman, grade ≥2+ pivot shift, and/or side-to-side KT-1000 laxity of >5 mm. The graft rupture rate was defined solely by the proportion of patients who had a graft rupture. Meta-analyses using the inverse variance method were used to estimate the pooled rates with 95% CIs. Subgroup analysis was conducted to compare allograft types and determine whether age, sex, and follow-up time influenced the estimates.

Results: A total of 14 studies met the inclusion criteria: 7 investigated bone–soft tissue allografts, 6 investigated soft tissue–only allografts, and 1 investigated both. The comparative study showed a difference in the cumulative failure rate between bone–patellar tendon–bone and soft tissue–only allografts. The pooled cumulative failure rates for bone–soft tissue and soft tissue–only allografts were 11% (95% CI, 7-17) and 20% (95% CI, 14-29), respectively ($P = .05$). The pooled graft rupture rates for bone–soft tissue and soft tissue–only allografts were 6% (95% CI, 4-9) and 13% (95% CI, 7-23), respectively ($P = .07$).

Conclusion: The meta-analysis results showed that bone–soft tissue allografts have lower cumulative failure rates than soft tissue–only allografts. Bone–soft tissue allografts may be the preferred allograft choices for ACLR.

Keywords: allograft; anterior cruciate ligament; anterior cruciate ligament injury; anterior cruciate ligament reconstruction

Anterior cruciate ligament (ACL) reconstruction (ACLR) has evolved over the past 2 decades, with surgeons utilizing different graft choices dependent on various factors such as patient age, activity level, and previous surgery. Traditionally, the use of the autograft has been the gold standard for young, athletic patients because of higher allograft reinjury rates.[4,19,46] However, in older, nonathletic patients, the higher risk of allograft reinjury demonstrated in younger patients diminishes.[19] A study on allograft ACLR reported an allograft reinjury rate of 3.5% in patients >34 years, similar to reported reinjury rates in autograft patients.[30] With acceptable outcomes in relatively lower-risk patient populations, allografts are an appealing graft choice because of decreased donor-site morbidity and operative time compared with autografts.[42] Common allograft graft choices for ACLR include those with an attached bone block, including bone–patellar tendon–bone (BPTB) and Achilles tendon-bone, and those

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composed of soft tissue only, including tibialis anterior or posterior, hamstring tendon (semitendinosus with or without gracilis), Achilles tendon without bone plug, and all–soft tissue quadriceps tendon. One concern with allograft tissue is a lack of incorporation into recipient bone.[35] It is also possible that soft tissue allograft may be less likely to incorporate into recipient bone, and this may affect clinical outcomes after allograft ACLR. While several allograft options exist for ACLR, there is no consensus regarding the optimal allograft options for this procedure. Therefore, this study aimed to specifically examine outcomes of ACLR performed with bone–soft tissue allografts and soft tissue–only allografts. We believe that a systematic review and meta-analysis of these types of allografts will yield significantly different clinical outcomes and failure rates between the 2 groups.

TABLE 1
Inclusion and Exclusion Criteria[a]

Inclusion
Published prospective or retrospective series describing outcomes of primary ACLR using allograft
Minimum follow-up of 2 years after primary ACLR
Use of nonirradiated graft
Exclusion
Examined only pediatric populations, all patients <18 years old
Laboratory or animal studies
Use of irradiated graft
Graft type or irradiation not explicitly defined
Reviews of original research
Non–peer reviewed studies

[a]ACLR, anterior cruciate ligament reconstruction.

METHODS

Literature Search and Study Selection

Two authors (A.T. and M.A.) performed a literature review using the PubMed, Scopus, and CINAHL databases. The search terms used can be seen in Appendix A (available in the online version of this article). The inclusion and exclusion criteria can be seen in Table 1. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram summarizing our literature search is presented in Figure 1.

Some studies meeting the inclusion criteria performed a comparative analysis between allografts and autografts; nonetheless, data on patients undergoing autograft ACLR were excluded from the present systematic review and meta-analysis. The level of evidence was determined as related to our research question.

Quality Assessment

The same 2 authors independently determined the methodologic quality of each study separately using the Delphi list score.[43] The Delphi list used the following 9 questions to score the quality assessment: (1) Was a method of randomization used? (2) Was the treatment allocation concealed? (3) Were the groups similar at baseline? (4) Was eligibility criteria specified? (5) Was the outcome assessor blinded? (6) Was the care provider blinded? (7) Was the patient blinded? (8) Were point estimates and measures of variability used? (9) Was there an intention-to-treat analysis? In this assessment, each study was given 1 point for yes, a 1-point deduction for no, and 0 points for "do not know." Disagreements were settled by consulting with the senior author (J.D.L.), a board-certified fellowship-trained orthopaedic surgeon.

Data Extraction

The 2 authors independently extracted data from the 14 studies used in this systematic review. Disagreements were settled by consulting with the senior author (J.D.L.). Study descriptive data included authors, journal, year published, procedure date range, country of origin, level of evidence, surgical approach, allograft type, and femoral and tibial fixation methods. Patient data included age, sex, follow-up length, and follow-up percentage. Outcome data included the graft failure and rupture incidence, the revision ACLR incidence, the Lachman grade, the pivot-shift grade, the overall International Knee

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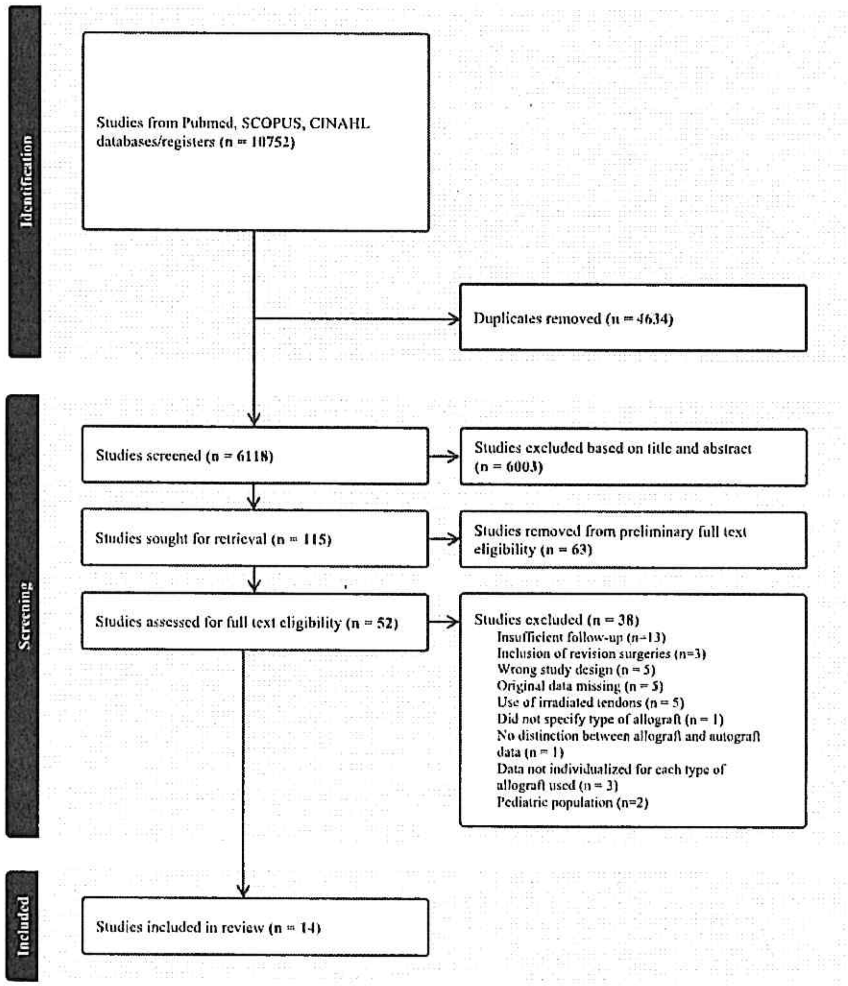

Figure 1. Flowchart demonstrating the process for inclusion and exclusion of articles.

Documentation Committee (IKDC) score, the Lysholm score, and the Tegner score.

Risk of Clinical Failure, Cumulative Failure, and Rupture

Failure in this study was defined in 2 ways: (1) cumulative failure rate and (2) graft rupture rate. The cumulative failure rate was defined as the accumulation of all patients that met the criteria for clinical failure as defined by Crawford et al.[12] This standardized risk is characterized by grade ≥2+ Lachman, grade ≥2+ pivot shift, overall IKDC grade C or D, graft rupture or tear, and/or instrumented laxity with a side-to-side difference >5 mm. The graft rupture rate isolated the graft rupture/tear component of the cumulative failure risk.

Statistical Analysis (Meta-Analysis)

The included studies were categorized by allograft type used for primary ACLR as follows: (1) bone–soft tissue, which included any allograft with an affixed bone plug, and (2) soft tissue only, with no affixed bone plug. To identify the effect of the "dosage" of bone plugs, additional analyses were performed to identify differences in graft failure among (1) double bone plug (BPTB), (2) single bone plug (Achilles tendon), and (3) soft tissue–only (hamstring tendon, tibialis anterior, and tibialis posterior) allografts. The following variables were extracted from each study when available and included in the analyses: number of knees, mean age (years), age (standard deviation), number of men, number of women, mean length of follow-up postoperatively (months), proportion at follow-up, Lachman grade at the final follow-up, pivot-shift grade at the final follow-up, number of cumulative graft failures, number of graft ruptures, total number of cases for each failure type (denominators), IKDC score, Lysholm score, and Tegner score (Appendix B, available online). Using the inverse variance method, random-effects meta-analysis models were used to calculate the rates/proportions and statistical parameters such as 95% CI.[7] Between study variance was calculated using the DerSimonian-Laird estimator.[13] Sensitivity analyses were conducted on sex, age, and follow-

TABLE 2
Study Characteristics[a]

Author (Year)	No. of Patients With Each Graft Type	Mean Age (Range), y	Sex	Follow-up, Mean (range), mo	% Follow-up	Delphi Score
Bone–soft tissue allografts						
Bach et al[2] (2005)	60 BPTB Allo (1 bilateral)	41 (18-61)	21 M 38 F	51 (26-170)	66	–3
Barrett et al[5] (2005)	38 BPTB Allo	47 (40-58)	20 M 18 F	36.4 (24-74)	100	–5
Mei et al[26] (2016)	24 dbl BPTB Allo 24 single BPTB Allo	36.5 (30-42)	17 M 31 F	36 (NR)	83	2
Peterson et al[29] (2001)	30 BPTB Allo	28 (15-55)	19 M 11 F	63 (55-78)	88	–6
Shah et al[32] (2010)	144 Achilles Allo w/bone	29.5 (NR)	75 M 69 F	40 (24-48)	91	–5
Siebold et al[34] (2003)	183 BPTB Allo 42 Achilles Allo w/bone	39.8 (15-69)	147 M 78 F	39 (24-74)	89.6	–5
Wang et al[45] (2011)	73 Achilles Allo w/bone 79 BPTB Allo	30.1 (20-43)	89 M 63 F	37 (25-55)	90	1
Niu et al[28] (2016)	50 dbl BPTB Allo 51 4 strand HT Allo	26.5 (21-31)	52 M 49 F	40 (36-48)	92	2
Soft tissue allografts						
Bottoni et al[8] (2015)	49 Tib Post Allo	29.2 (20.7-41.5)	43 M 6 F	136 (120-132)	98	0
Edgar et al[14] (2008)	47 4-strand HT Allo	31 (15-55)	26 M 20 F	48 (36-64)	97.9	–2
Rai et al[31] (2018)	107 2 Tib Ant	30.5 (18-54)	75 M 32 F	49.77 (30-70)	90	–5
Shybut et al[33] (2013)	19 Tib Ant Allo	39.9 (19-60)	12 M 7 F	32.4 (24-38)	100	–3
Singhal et al[36] (2007)	69 Tib Ant Allo	31.7 (19-69)	38 M 31 F	55 (42-74)	55	–5
Snow et al[37] (2010)	64 dbl Tib Ant Allo	27 (16-55)	33 M 31 F	44.5 (24-55)	88	–3

[a]A few patient characteristics were based on the initial patient group, not those who just completed the follow-up. Allo, allograft; BPTB, bone–patellar tendon–bone; dbl, double; F, female; HT, hamstring tendon; M, male; NR, not reported; Tib Ant, tibialis anterior; Tib Post, tibialis posterior; w/bone, bone plug left attached to Achilles tendon allograft.

up length to identify potential differences in the subgroups that may influence pooled effects. All statistical analyses and calculations were performed using the packages metafor[44] and meta[3] with the statistical software environment R (Rstudio Version, 1.2.1335; R Foundation for Statistical Computing). Statistical significance was established at $P < .05$.

RESULTS

Study Characteristics

Fourteen studies were included. Characteristics for each study are presented in Table 2. The mean age of the patients who underwent bone–soft tissue allograft ACLR was 37.4 (range, 15-69 years), and the mean age for patients who underwent soft tissue–only allograft ACLR was 30.8 (range, 15-69 years). The mean follow-up duration for the bone–soft tissue allograft group was 42.8 months (range, 24-170 months) and 60.9 months (range, 24-132 months) for the soft tissue–only allograft group. The bone–soft tissue allograft group had a follow-up percentage of 87.5%, while the follow-up percentage in the soft tissue–only allograft group was 88.2%. Also, 44.8% of the patients in the bone–soft tissue allograft group were women.

Surgical Characteristics

The surgical technique—including graft type, femoral and tibial fixation methods, and surgical approach—are described in Table 3. The studies included utilized the following graft types: 7 studies [2,5,26,29,32,34,45] included bone–soft tissue allografts (4 BPTB, 3 BPTB or Achilles with bone block), 6 studies included soft tissue–only allografts (1 study included hamstring tendon, 4 studies included tibialis anterior, and 1 study included tibialis posterior),[8,14,31,33,36,37] and 1 comparative study included BPTB and 4-strand hamstring tendon allografts.[28]

TABLE 3
Surgical Details[a]

Study	Graft Type Used	Approach	Tibial Fixation	Femoral Fixation
Bach et al[2] (2005)	BPTB	Endoscopic (56), dual-incision (3)	Metal interference	Metal interference
Barrett et al[5] (2005)	BPTB	Endoscopic	Interference screws + post or button + post	Interference screws or cortical button
Bottoni et al[8] (2015)	Tib Post	Endoscopic	Bioabsorbable interference screw	Metal cross-pin
Edgar et al[14] (2008)	Hamstring	Endoscopic	Bioabsorbable interference screw + spiked washer and screw	Interference screw + continuous loop cortical button
Mei et al[26] (2016)	dbl BPTB Allo single BPTB Allo	Endoscopic	2 interference screws	2 interference screws
Niu et al[28] (2016)	dbl BPTB Allo 4-strand HT Allo	Endoscopic	2 bioabsorbable interference screws	BPTB, 2 bioabsorbable interference screws; HT-cortical button flipped over lateral femoral cortex
Peterson et al[29] (2001)	BPTB Allo	Endoscopic	Metal interference fit screws	Metal interference fit screws
Rai et al[31] (2018)	4 HT Auto 2 Tib Ant	Endoscopic	Bioabsorbable interference screw	Cortical button or cross-pin
Shah et al[32] (2010)	Achilles Allo	Endoscopic	BioMet washerlock system	Cannulated metal or bioabsorbable interference screw
Shybut et al[33] (2013)	Tib Ant Allo	Endoscopic	Depuy-Mitek Intrafix Sheath and screw	Depuy-Mitek Rigidfix or Arthrex Transfix
Siebold et al[34] (2003)	BPTB Allo Achilles Allo	Endoscopic	BPTB, titanium interference screw; Achilles, staples +/- titanium interference screw	BPTB, titanium interference screw; Achilles, bone plug
Singhal et al[36] (2007)	Tib Ant Allo	Endoscopic	Bioabsorbable interference screw	Bioabsorbable interference screw
Snow et al[37] (2010)	Dbl Tib Ant Allo	NR	Bioabsorbable interference screw	Cortical button and cross-pin
Wang et al[45] (2011)	Achilles Allo BPTB Allo	Endoscopic	BPTB, biodegradable interference screw (external aperture); Achilles, biodegradable interference screw + cortical screw w/ spiked washer	Biodegradable interference screws

[a]Allo, allograft; Auto, autograft; BPTB, bone–patellar tendon–bone; dbl, double; HT, hamstring tendon; NR, not reported; Tib Ant, tibialis anterior; Tib Post, tibialis posterior.

Cumulative Failure Rates for Bony Versus Soft Tissue–Only Allografts

The cumulative failure for each study is detailed in Table 4. The pooled cumulative failure rate for bone–soft tissue allografts was 11% (95% CI, 7-17), and the pooled cumulative failure rate for soft tissue–only allografts was 20% (95% CI, 14-29) (Figure 2). The risk of cumulative failure was significantly greater in the soft tissue–only group compared with the bone–soft tissue group (χ^2 = 3.92; P = .05).

Rates of Graft Rupture for Bony Versus Soft Tissue–Only Allografts

The graft rupture rate for each study is detailed in Table 4. The pooled graft rupture rate for bone–soft tissue allografts was 6% (95% CI, 4-9), and the pooled graft rupture rate for soft tissue–only allografts was 13% (95% CI, 7-23) (Figure 3). The risk of graft rupture was similar in both groups (χ^2 = 3.39; P = .07).

Cumulative Failure Rates for Double Bone Plug, Single Bone Plug, and Soft Tissue–Only Allografts

The pooled cumulative failure rate for double bone plug allografts was 13% (95% CI, 9-17), the pooled cumulative failure rate for soft tissue–only allografts was 20% (95% CI, 14-27), and the pooled cumulative failure rate for single bone plug allografts was 11% (95% CI, 4-27) (Figure 4). There were no differences among graft types with regard to cumulative failure rate (χ^2 = 3.89; P = .14).

TABLE 4
Failure Risk[a,b]

	Defined Method of Failure											
Author	Graft Rupture	KT-1000	Revision ACL Surgery	(+) Pivot Shift	Other[d]	Clinical Failure (%)	Abnormal/Positive Pivot-Shift Grade	Abnormal Instrumental Laxity	Abnormal Lachman	IKDC Grade C Grade D	Rupture Rate	Cumulative Failure Risk[c]
Bone–soft tissue allografts												
Bach et al[3] (2005)		X		X		10	6/60	0/60	4/60	0/60	1/61	7/61 (11.48)
Barrett et al[5] (2005)		X	X	X	X	2.60	1/38	3/38	1/38	5/38	NR	5/38 (13.16)
Mei et al[26] (2016)		X				0	1/48	0/48	0/48	NR	2/48	3/48 (6.25)
Peterson et al[29] (2001)					X	3.60	1/30	0/30	3/30	NR	1/30	3/30 (10)
Shah et al[32] (2010)	X				X	5.60	NR	1/144	NR	8/144	7/144	8/144 (5.6)
Siebold et al[34] (2003)	X	X				14.75 (P), 7.3 (A)	NR	8/164 (P); 1/40 (A)	NR	45/183 (P); 10/42 (A)	19/183 (P); 2/42 (A)	45/183 (24.59) (P); 10/42 (23.81) (A)
Wang et al[45] (2011)	X	X				5.1 (P); 1.4 (A)	NR	4/79 (P); 1/73 (A)	NR	19/79 (P); 16/73 (A)	5/79 (P); 1/73 (A)	19/79 (24.05) (P); 16/73 (21.92) (A)
Niu et al[28] (2016)	X	X				4 (P); 17.6 (H)	1/49 (P); 4/47 (H)	1/49 (P); 5/47 (H)	1/49 (P); 5/47 (H)	NR	1/49 (P) 4/47 (H)	2/49 (4.08) (P); 9/47 (19.15) (H)
Soft tissue allografts												
Bottoni et al[8] (2015)			X			26.50	NR	NR	NR	8/49	13/49	15/49 (30.61)
Edgar et al[14] (2008)		X			X	8	NR	1/47	NR	8/47	NR	8/47 (17.02)
Heath et al[17] (2019)	X				X	21.40	NR	NR	NR	NR	53/247	53/247 (21.40)
Larson et al[22] (2016)	X	X				37.50	NR	0/8	NR	NR	3/8	3/8 (37.50)
Rai et al[31] (2018)	X					12.14	1/107	NR	9/107	6/107	13/107	13/107 (12.14)
Shybut et al[33] (2013)		X				21	1/19	4/19	1/19	NR	1/19	4/19 (21.05)
Singhal et al[36] (2007)			X			23.10	NR	NR	NR	6/43	16/69	22/69 (31.88)
Snow et al[37] (2010)	X					8	1/25	0/25	NR	3/59	5/64	8/64 (12.5)

[a]A, Achilles allograft; ACL, anterior cruciate ligament; IKDC, International Knee Documentation Committee; H, 4-strand hamstring allograft; NR, not reported; P, bone–patellar tendon–bone allograft; X, denotes defined method of failure within each repsective.
[b]Total values may differ due to attrition in original studies.
[c]Cumulative failure involves overlapping patients between different clinical failure outcome measures.
[d]Ligamentous laxity, Lachman score, degree of improvement from preoperative, Lysholm score, contralateral ACL injury.

Rates of Graft Rupture for Double Plug, Single Plug, and All–Soft Tissue Allografts

The pooled rerupture rate for double bone plug allografts was 8% (95% CI, 5-12), the pooled rerupture rate for soft tissue–only allografts was 13% (95% CI, 7-23), and the pooled rerupture rate for single bone plug allografts was 4% (95% CI, 2-8) (Figure 5). A significant difference was observed among graft types for the rerupture rate (χ^2 = 6.03; P = .05). Pairwise comparisons showed that the rerupture risk was significantly lower with single bone plug grafts compared with soft tissue–only grafts (χ^2 = 5.86; P = .02). There were no differences in other pairwise comparisons with regard to rerupture risk (P > .05).

Moderator Analyses for Bony Versus All–Soft Tissue Allografts

Graft Rupture Rate

Significant moderator effects were found for sex (Q = 5.10; P = .02), the Tegner score (Q = 3.93; P = .05), and the follow-up length (Q = 7.26; P = .01). Overall, studies with a larger proportion of women were associated with lower rerupture rates. However, when separated by graft type, the moderator effects were nonsignificant (bony: Q = 1.59, P = .21; soft tissue: Q = 1.35, P = .25). Overall, studies with higher mean Tegner scores were associated with lower rerupture rates. When separated by graft type, the Tegner score was a significant moderator in the soft tissue group (Q = 9.31; P = .002) but not the bone–soft tissue group (Q = 0.53; P = .47). Overall, studies with longer follow-up times were associated with higher rerupture rates. However, when separated by graft type, the moderator effects were nonsignificant (bony: Q = 1.09, P = .30; soft tissue: Q = 3.08, P = .08). A caveat to all these significant moderator effects is that 1 study (Bottoni et al[8]) seemed to be significantly influencing these moderator effects, as when it was removed, all moderator effects became nonsignificant.

There were differences between allograft groups with regard to sex, Tegner score, and follow-up length. A larger proportion of women was associated with lower rerupture rates in the soft tissue–only group (Q = 7.10; P = .02).

Study or Subgroup	Events	Total	Weight	IV, Random, 95% CI
Two.group.graft.type = Bony				
Bach et al	7	61	6.7%	0.11 (0.05–0.22)
Mei et al	3	48	4.8%	0.06 (0.01–0.17)
Niu et al	2	50	3.9%	0.04 (0.00–0.14)
Peterson et al	3	30	4.7%	0.10 (0.02–0.27)
Shah et al	8	144	7.1%	0.06 (0.02–0.11)
Siebold et al	27	183	8.8%	0.15 (0.10–0.21)
Siebold et al	3	42	4.8%	0.07 (0.01–0.19)
Wang et al	19	73	8.2%	0.26 (0.16–0.38)
Wang et al	16	79	8.0%	0.20 (0.12–0.31)
Total (95% CI)		**710**	**57.0%**	**0.11 (0.07–0.17)**
Heterogeneity: Tau^2 = 0.3464; Chi^2 = 26.87, df = 8 (P < .001); I^2 = 70%				
Two.group.graft.type = Soft tissue				
Bottoni et al	15	49	7.7%	0.31 (0.18–0.45)
Niu et al	9	51	7.1%	0.18 (0.08–0.31)
Rai et al	13	107	7.9%	0.12 (0.07–0.20)
Shybut et al	4	19	5.1%	0.21 (0.06–0.46)
Singhal et al	22	69	8.3%	0.32 (0.21–0.44)
Snow et al	8	64	7.0%	0.12 (0.06–0.23)
Total (95% CI)		**359**	**43.0%**	**0.20 (0.14–0.29)**
Heterogeneity: Tau^2 = 0.2152; Chi^2 = 15.39, df = 5 (P = .009); I^2 = 68%				
Total (95% CI)		**1069**	**100.0%**	**0.15 (0.11–0.20)**

Heterogeneity: Tau^2 = 0.3361; Chi^2 = 49.75, df = 14 (P < .001); I^2 = 72%
Test for subgroup differences: Chi^2 = 3.92, df = 1 (P = .05)

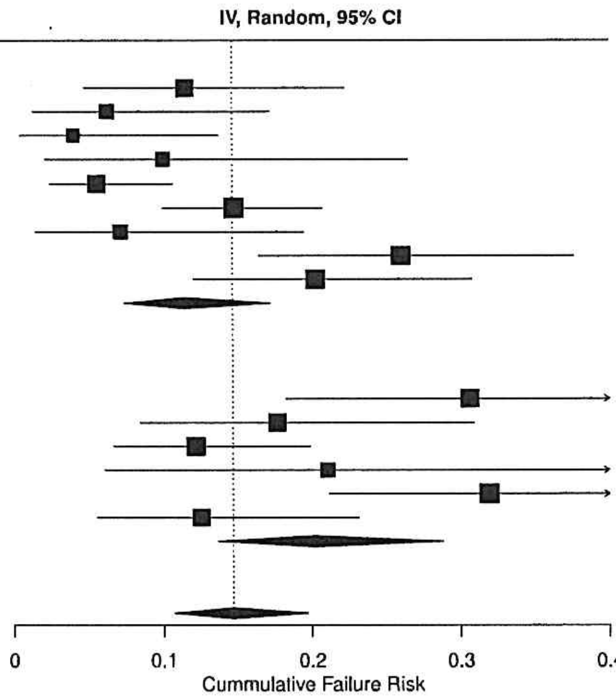

Figure 2. Forest plot demonstrating cumulative failure rates for bone–soft tissue grafts (top) and soft tissue–only grafts (bottom). IV, inverse variance.

Study or Subgroup	Events	Total	Weight	IV, Random, 95% CI
Two.group.graft.type = Bony				
Bach et al	1	61	3.7%	0.02 (0.00–0.09)
Mei et al	2	24	5.4%	0.08 (0.01–0.27)
Niu et al	4	51	7.3%	0.08 (0.02–0.19)
Peterson et al	1	30	3.7%	0.03 (0.00–0.17)
Shah et al	7	144	8.7%	0.05 (0.02–0.10)
Siebold et al	19	183	10.2%	0.10 (0.06–0.16)
Siebold et al	2	42	5.5%	0.05 (0.01–0.16)
Wang et al	1	73	3.7%	0.01 (0.00–0.07)
Wang et al	5	79	7.9%	0.06 (0.02–0.14)
Total (95% CI)		**687**	**56.0%**	**0.06 (0.04–0.09)**
Heterogeneity: Tau^2 = 0.0976; Chi^2 = 10.3, df = 8 (P = .24); I^2 = 22%				
Two.group.graft.type = Soft tissue				
Bottoni et al	13	49	9.4%	0.27 (0.15–0.41)
Niu et al	1	50	3.7%	0.02 (0.00–0.11)
Rai et al	13	107	9.6%	0.12 (0.07–0.20)
Shybut et al	1	19	3.6%	0.05 (0.00–0.26)
Singhal et al	16	69	9.8%	0.23 (0.14–0.35)
Snow et al	5	64	7.9%	0.08 (0.03–0.17)
Total (95% CI)		**358**	**44.0%**	**0.13 (0.07–0.23)**
Heterogeneity: Tau^2 = 0.5232; Chi^2 = 17.01, df = 5 (P = .004); I^2 = 71%				
Total (95% CI)		**1045**	**100.0%**	**0.08 (0.05–0.12)**

Heterogeneity: Tau^2 = 0.4908; Chi^2 = 44.82, df = 14 (P < .001); I^2 = 69%
Test for subgroup differences: Chi^2 = 3.39, df = 1 (P = .07)

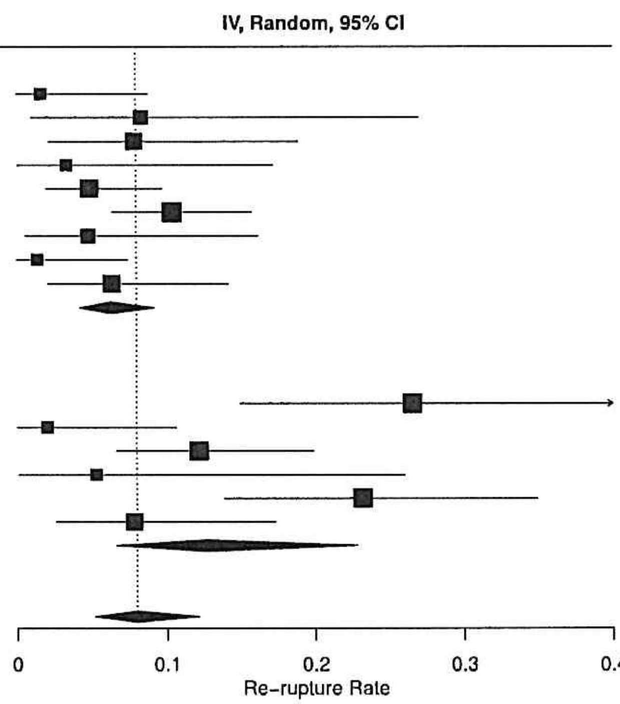

Figure 3. Forrest plot demonstrating rates of rupture for bone–soft tissue grafts (top) and soft tissue–only grafts (bottom). IV, inverse variance.

Study or Subgroup	Events	Total	Weight	IV, Random, 95% CI
Three.group.graft.type = Double				
Bach et al	7	61	5.9%	0.11 (0.05–0.22)
Barrett et al	5	38	5.1%	0.13 (0.04–0.28)
Mei et al	3	48	4.1%	0.06 (0.01–0.17)
Niu et al	2	50	3.3%	0.04 (0.00–0.14)
Peterson et al	3	30	4.0%	0.10 (0.02–0.27)
Siebold et al	27	183	8.1%	0.15 (0.10–0.21)
Wang et al	16	79	7.3%	0.20 (0.12–0.31)
Total (95% CI)		**489**	**37.7%**	**0.13 (0.09–0.17)**
Heterogeneity: $Tau^2 = 0.0746$; $Chi^2 = 9.14$, df = 6 (P = .17); $I^2 = 34\%$				
Three.group.graft.type = All soft tissue				
Bottoni et al	15	49	6.9%	0.31 (0.18–0.45)
Edgar et al	8	47	6.1%	0.17 (0.08–0.31)
Niu et al	9	51	6.3%	0.18 (0.08–0.31)
Rai et al	13	107	7.1%	0.12 (0.07–0.20)
Shybut et al	4	19	4.4%	0.21 (0.06–0.46)
Singhal et al	22	69	7.5%	0.32 (0.21–0.44)
Snow et al	8	64	6.2%	0.12 (0.06–0.23)
Total (95% CI)		**406**	**44.4%**	**0.20 (0.14–0.27)**
Heterogeneity: $Tau^2 = 0.1786$; $Chi^2 = 15.8$, df = 6 (P = .01); $I^2 = 62\%$				
Three.group.graft.type = Single				
Shah et al	8	144	6.3%	0.06 (0.02–0.11)
Siebold et al	3	42	4.1%	0.07 (0.01–0.19)
Wang et al	19	73	7.4%	0.26 (0.16–0.38)
Total (95% CI)		**259**	**17.8%**	**0.11 (0.04–0.28)**
Heterogeneity: $Tau^2 = 0.8847$; $Chi^2 = 17.7$, df = 2 (P < .001); $I^2 = 89\%$				
Total (95% CI)		**1154**	**100.0%**	**0.15 (0.11–0.19)**
Heterogeneity: $Tau^2 = 0.2794$; $Chi^2 = 50.10$, df = 16 (P < .001); $I^2 = 68\%$				
Test for subgroup differences: $Chi^2 = 3.89$, df = 2 (P = .14)				

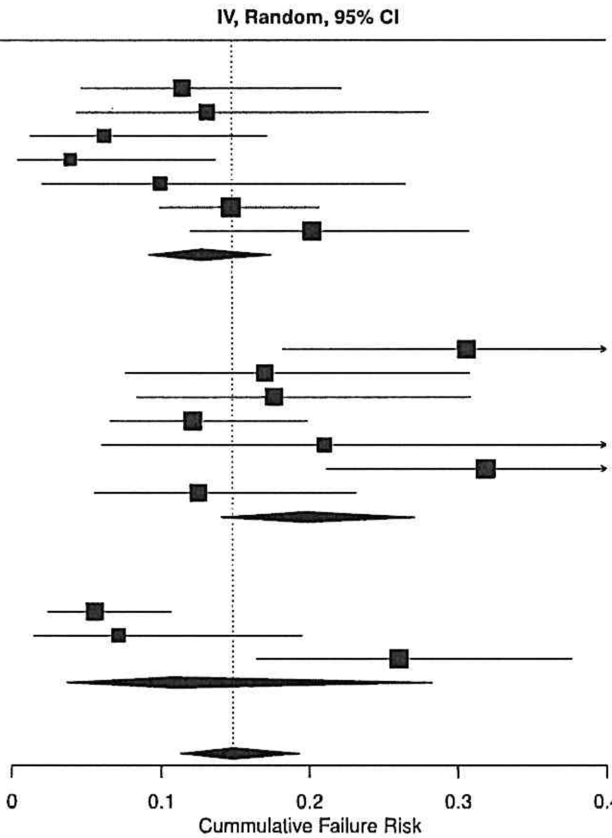

Figure 4. Forest plot demonstrating cumulative failure rates for double bone plug (top), soft tissue–only (middle), and single bone plug (bottom) grafts. IV, inverse variance.

The follow-up duration was longer in the soft tissue–only group compared with the bone–soft tissue group (Q = 7.14; *P* = .008). There was a significant effect of follow-up length on the rerupture rate in the soft tissue–only group (Q = 7.26; *P* = .007). In the metaregression analysis, a longer follow-up period was associated with higher cumulative failure rates. After removing 1 outlier,[8] the effect of follow-up was no longer significant. No differences were found between allograft groups with regard to age, Tegner score, or Lysholm score.

Cumulative Failure Rate

There were no significant moderator effects with regard to sex, age, follow-up length, Tegner score, or Lysholm score.

Postoperative Patient-Reported Outcomes

The mean Lysholm scores for bone–soft tissue allografts ranged from 82 to 91.3 at the follow-up, while the mean Lysholm scores for soft tissue allografts ranged from 79.7 to 92.8 at the follow-up. Reported means did not differ by graft type (Q = 0.002; *P* = .97). One bone–soft tissue allograft study and 3 soft tissue–only allograft studies did not report Lysholm scores.

The mean Tegner scores for bone–soft tissue allografts ranged from 3.9 to 7.2, while the mean Tegner scores for soft tissue–only allografts ranged from 4.4 to 6.9. Reported means did not differ by graft type (Q = 0.40; *P* = .526). Three bone–soft tissue allograft studies and 2 soft tissue–only allograft studies, in addition to the comparative study, did not report Tegner scores. The IKDC scores for available studies can be seen in Appendix B (available online).

DISCUSSION

The most important finding in this systematic review and meta-analysis is that soft tissue–only allografts appear to have higher cumulative failure rates when compared with bone–soft tissue allografts. While there was no significant difference between graft types with regard to the rerupture rate, the difference did approach significance in favor of bony grafts. In our additional analyses investigating the effect of bone plug dosage (ie, single versus double bone plug), we found no differences between double plug, single plug, and soft tissue–only grafts with regard to cumulative failure. We also found that single bone plug grafts resulted in lower rerupture rates than all soft tissue grafts. These

Study or Subgroup	Events	Total	Weight	IV, Random, 95% CI
Three.group.graft.type = Double				
Bach et al	1	61	3.7%	0.02 (0.00–0.09)
Mei et al	2	24	5.4%	0.08 (0.01–0.27)
Niu et al	4	51	7.3%	0.08 (0.02–0.19)
Peterson et al	1	30	3.7%	0.03 (0.00–0.17)
Siebold et al	19	183	10.2%	0.10 (0.06–0.16)
Wang et al	5	79	7.9%	0.06 (0.02–0.14)
Total (95% CI)		**428**	**38.1%**	**0.08 (0.05–0.12)**
Heterogeneity: Tau^2 = 0.0327; Chi^2 = 5.17, df = 5 (P = .40); I^2 = 3%				
Three.group.graft.type = All soft tissue				
Bottoni et al	13	49	9.4%	0.27 (0.15–0.41)
Niu et al	1	50	3.7%	0.02 (0.00–0.11)
Rai et al	13	107	9.6%	0.12 (0.07–0.20)
Shybut et al	1	19	3.6%	0.05 (0.00–0.26)
Singhal et al	16	69	9.8%	0.23 (0.14–0.35)
Snow et al	5	64	7.9%	0.08 (0.03–0.17)
Total (95% CI)		**358**	**44.0%**	**0.13 (0.07–0.23)**
Heterogeneity: Tau^2 = 0.5232; Chi^2 = 17.01, df = 5 (P = .004); I^2 = 71%				
Three.group.graft.type = Single				
Shah et al	7	144	8.7%	0.05 (0.02–0.10)
Siebold et al	2	42	5.5%	0.05 (0.01–0.16)
Wang et al	1	73	3.7%	0.01 (0.00–0.07)
Total (95% CI)		**259**	**17.9%**	**0.04 (0.02–0.08)**
Heterogeneity: Tau^2 = 0; Chi^2 = 1.49, df = 2 (P = .47); I^2 = 0%				
Total (95% CI)		**1045**	**100.0%**	**0.08 (0.05–0.12)**
Heterogeneity: Tau^2 = 0.4908; Chi^2 = 44.82, df = 14 (P < .001); I^2 = 69%				
Test for subgroup differences: Chi^2 = 6.03, df = 2 (P = .05)				

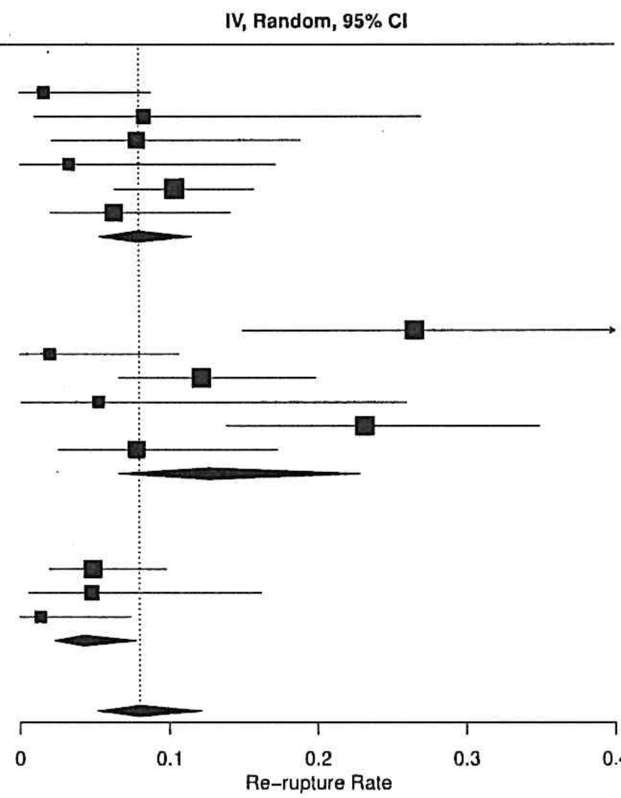

Figure 5. Forest plot demonstrating rerupture rates for double bone plug (top), soft tissue–only (middle), and double single plug (bottom) grafts. IV, inverse variance.

findings are important because they may help guide specific graft choices when considering the use of allograft ACLR in a subset of adult patients with functional instability after ACL injury. Additional prospective comparative studies will be necessary to confirm these findings.

Previous studies have shown that a wide spectrum of allografts have been clinically used for ACLR, including various bone-block and soft tissue–only allografts.[20,21,23] However, only 1 included study directly compared failure rates between a bone block and a soft tissue allograft.[28] In that study, which compared BPTB allografts with quadrupled hamstring allografts, the authors reported lower failure rates after BPTB and significantly improved patient-reported outcome scores, including the IKDC score.[28] Meanwhile, a systematic review by Joyce et al[18] found no differences in clinical outcomes when comparing BPTB and soft tissue allografts. Interestingly, the findings of the present study differ from those of Joyce et al, with our findings indicating a lower clinical failure rate and a lower graft rupture rate in bone–soft tissue allografts compared with soft tissue–only allografts. One explanation for this is that the single comparative study within each respective systematic review had differing findings on the failure rates of each type of allograft.[23,28] The single comparative study[23] included in Joyce et al compared BTPB and soft tissue allografts and found no differences in graft failure risk, instrumented laxity, Lachman or pivot-shift grades, or overall IKDC score. This study was excluded from the present systematic review and meta-analysis because it did not explicitly define clinical failure or provide the number or proportion of patients with graft failure.[23] In addition, the pooled failure rates for BPTB and soft tissue allografts in Joyce et al was based on cumulative failure rates that relied heavily on patient-reported outcomes. Finally, some of the studies included in that review did not contain any information on graft rupture and were therefore excluded from our study.[5,27,38-41] When comparing the studies included by Joyce et al with those in our study, only 5 studies overlapped (4 bone–soft tissue, 1 soft tissue). In addition, the article search in Joyce et al was performed up to April 2014, while the present review included 4 studies (including 1 comparative study) published after this date. Another key difference between the present investigation and Joyce et al is that we grouped all bone–soft tissue allografts together and soft tissue–only allografts separately. This was done because we suspect that all–soft tissue allografts may incorporate into host bone more slowly than bone–soft tissue allografts, which may affect clinical outcomes, including failure rates.[11]

After analyzing the studies that matched our inclusion criteria, we determined a difference between bone–soft tissue and soft tissue–only allografts in terms of both graft rupture and cumulative failure rates. The differences in cumulative failure rates between allograft types could be, in part, due to the cumulative failure definition encompassing a wide spectrum of clinical outcome measurements, with reported outcomes varying among included studies. For this reason, the graft rupture rate was separately reported in this study so that graft failure could be isolated to a universal outcome used by most studies. Overall, the differences in failure among allograft types are likely due to differences in graft incorporation and fixation method. Soft tissue allograft may be less likely to incorporate into the recipient's bone, contributing to increased graft failure after allograft ACLR. Graft-to-bone integration is critical for optimal healing after ACLR,[9] and early biomechanical and histological animal studies have demonstrated increased strength and speed of bone-to-bone healing as compared with tendon-to-bone healing.[1,25] In regard to fixation method, soft tissue–only allograft fixation was more often suspensory, which has been demonstrated to lead to increased femoral and tibial tunnel widening because of bungee-cord and windshield-wiper effects and inferior soft tissue–to-bone healing.[6,16,24] This may have contributed to the higher failure rates demonstrated in soft tissue–only allografts. With regard to graft rupture, the soft tissue allograft group had a mean follow-up period that was longer than the bone-block group, most likely due to the disproportionate effect of 1 study with an unusually long follow-up period of 10 years.[8] The longer follow-up period could contribute to an increased number of graft failures due to the passage of time. Not only was the graft rupture rate of bone–soft tissue allografts lower than all–soft tissue allografts in this analysis, but it was also lower than some previously reported autograft rates. For example, in a study by Getgood et al,[15] the reported rupture rate for hamstring autografts without lateral extra-articular tenodesis at a 24-month follow-up was 11%, compared with this study's bone–soft tissue allograft rupture rate of 6%. The lower graft rupture rate of the bone–soft tissue allograft in this analysis is likely due to the inclusion of an older, less active population as compared with the study by Getgood et al that included only more active patients aged ≤25 years.

When comparing single bone plug with double bone plug allograft ACLR, the present meta-analysis found no significant difference in failure rates. This is in contrast to previous studies, including 2 studies in the analysis—Wang et al[45] and Siebold et al[34]—that found that single bone plug (Achilles tendon allograft) had lower revision rates than double bone plug (BPTB) allograft ACLR. However, the improved failure rates of the single bone plug Achilles tendon allograft may be due more to its higher maximum tensile strength compared with BPTB rather than the effect of the bone plug.[10,34] In the present analysis, the pooled failure rates of single bone plug allograft ACLR were lower than double bone plug allograft ACLR (4% vs 8%); however, the difference was not significant, likely due to a small sample size and, therefore, underpowered statistical analyses. This suggests that there is a need for more studies that compare single versus double bone plug graft rupture rates to more definitively conclude the ideal dosage of bone plug for allograft ACLR.

This study does have limitations. Regarding our patient-reported outcomes, we did not have enough studies that used the same measurements, and as a result, we could not use the Lysholm, Tegner, or IKDC scores to confirm our findings from the allograft failure data. Because the data on these measures were sparse and there were differences in outcomes reported by the study, the moderator analyses showed differences in Tegner scores by graft type. In addition, concomitant intra-articular injuries varied greatly between studies, potentially altering the outcomes of different studies. Finally, similar to moderator analyses on Tegner scores, there were differences in moderator analyses between graft types for graft failure rate by sex and length of follow-up. Again, these differences were likely due to the type of information reported in each study. Ultimately, our systematic review only included 1 comparative study involving a bone block and a soft tissue allograft, limiting our control over other factors such as age, body mass index, concomitant injuries, and so forth. Having only 1 comparative study also highlights the need for more comparative studies on different allografts that focus on clinical outcomes and allograft failure.

CONCLUSION

Bone–soft tissue allografts appear to have lower all-cause failure rates and lower graft retear rates than soft tissue–only allografts. Bone–soft tissue allografts may be the preferred allograft choices for ACLR in adults after ACL injury.

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REFERENCES

1. Amano H, Tanaka Y, Kita K, et al. Significant anterior enlargement of femoral tunnel aperture after hamstring ACL reconstruction, compared to bone–patellar tendon–bone graft. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(2):461-470.
2. Bach BR Jr, Aadalen KJ, Dennis MG, et al. Primary anterior cruciate ligament reconstruction using fresh-frozen, nonirradiated patellar tendon allograft: minimum 2-year follow-up. *Am J Sports Med*. 2005;33(2):284-292.
3. Balduzzi S, Rücker G, Schwarzer G. How to perform a meta-analysis with R: a practical tutorial. *BMJ Ment Health*. 2019;22(4):153-160.
4. Barber FA, Cowden CH III, Sanders EJ. Revision rates after anterior cruciate ligament reconstruction using bone–patellar tendon–bone allograft or autograft in a population 25 years old and younger. *Arthroscopy*. 2014;30(4):483-491.
5. Barrett G, Stokes D, White M. Anterior cruciate ligament reconstruction in patients older than 40 years: allograft versus autograft patellar tendon. *Am J Sports Med*. 2005;33(10):1505-1512.
6. Baumfeld JA, Diduch DR, Rubino LJ, et al. Tunnel widening following anterior cruciate ligament reconstruction using hamstring autograft: a comparison between double cross-pin and suspensory graft fixation. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(12):1108-1113.

7. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth Methods.* 2010;1(2):97-111.
8. 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.
9. Chen CH. Graft healing in anterior cruciate ligament reconstruction. *Sports Med Arthrosc Rehabil Ther Technol.* 2009;1(1):21.
10. Cooper DE, Deng XH, Burstein AL, Warren RF. The strength of the central third patellar tendon graft: a biomechanical study. *Am J Sports Med.* 1993;21(6):818-823.
11. Cooper RR, Misol S. Tendon and ligament insertion. A light and electron microscopic study. *J Bone Joint Surg Am.* 1970;52(1):1-20.
12. Crawford SN, Waterman BR, Lubowitz JH. Long-term failure of anterior cruciate ligament reconstruction. *Arthroscopy.* 2013;29(9):1566-1571.
13. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials.* 1986;7(3):177-188.
14. Edgar CM, Zimmer S, Kakar S, Jones H, Schepsis AA. Prospective comparison of auto and allograft hamstring tendon constructs for ACL reconstruction. *Clin Orthop Relat Res.* 2008;466(9):2238-2246.
15. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the STABILITY Study Randomized Clinical Trial. *Am J Sports Med.* 2020;48(2):285-297.
16. Giorgio N, Moretti L, Pignataro P, et al. Correlation between fixation systems elasticity and bone tunnel widening after ACL reconstruction. *Muscles Ligaments Tendons J.* 2016;6(4):467-472.
17. Heath EL, Salmon LJ, Cooper R, et al. 5-year survival of pediatric anterior cruciate ligament reconstruction with living donor hamstring tendon grafts. *Am J Sports Med.* 2019;47(1):41-51.
18. Joyce CD, Randall KL, Mariscalco MW, Magnussen RA, Flanigan DC. Bone–patellar tendon–bone versus soft-tissue allograft for anterior cruciate ligament reconstruction: a systematic review. *Arthroscopy.* 2016;32(2):394-402.
19. Kaeding CC, Aros B, Pedroza A, et al. Allograft versus autograft anterior cruciate ligament reconstruction: predictors of failure from a MOON Prospective Longitudinal Cohort. *Sports Health.* 2011;3(1):73-81.
20. Kang HJ, Wang XJ, Wu CJ, et al. Single-bundle modified patellar tendon versus double-bundle tibialis anterior allograft ACL reconstruction: a prospective randomized study. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(8):2244-2249.
21. Kim SJ, Bae JH, Lim HC. Comparison of Achilles and tibialis anterior tendon allografts after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2014;22(1):135-141.
22. Larson CM, Heikes CS, Ellingson CI, et al. Allograft and autograft transphyseal anterior cruciate ligament reconstruction in skeletally immature patients: outcomes and complications. *Arthroscopy.* 2016;32(5):860-867.
23. Lee JH, Bae DK, Song SJ, Cho SM, Yoon KH. Comparison of clinical results and second-look arthroscopy findings after arthroscopic anterior cruciate ligament reconstruction using 3 different types of grafts. *Arthroscopy.* 2010;26(1):41-49.
24. Lee TJ, Jang KM, Kim TJ, Lee SM, Bae JH. Adjustable-loop cortical suspensory fixation results in greater tibial tunnel widening compared to interference screw fixation in primary anterior cruciate ligament reconstruction. *Medicina.* 2022;58(9):1193.
25. Ma Y, Murawski CD, Rahnemai-Azar AA, et al. Graft maturity of the reconstructed anterior cruciate ligament 6 months postoperatively: a magnetic resonance imaging evaluation of quadriceps tendon with bone block and hamstring tendon autografts. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(3):661-668.
26. Mei X, Zhang Z, Yang J. Double-layer versus single-layer bone-patellar tendon-bone anterior cruciate ligament reconstruction: a prospective randomized study with 3-year follow-up. *Arch Orthop Trauma Surg.* 2016;136(12):1733-1739.
27. Melberg MW, Indelicate PA. Fresh-frozen allograft experience. *Sports Med Arthrosc Rev.* 1993;1(1):77-88.
28. Niu Y, Niu C, Wang X, et al. Improved ACL reconstruction outcome using double-layer BPTB allograft compared to that using four-strand hamstring tendon allograft. *Knee.* 2016;23(6):1093-1097.
29. Peterson RK, Shelton WR, Bomboy AL. Allograft versus autograft patellar tendon anterior cruciate ligament reconstruction: a 5-year follow-up. *Arthroscopy.* 2001;17(1):9-13.
30. Petit CB, Diekfuss JA, Warren SM, et al. Allograft anterior cruciate ligament reconstruction fails at a greater rate in patients younger than 34 years. *Sports Med Arthrosc Rehabil Ther Technol.* 2023;5(4):100741.
31. Rai S, Jin SY, Rai B, et al. A single bundle anterior cruciate ligament reconstruction (ACL-R) using hamstring tendon autograft and tibialis anterior tendon allograft: a comparative study. *Curr Med Sci.* 2018;38(5):818-826.
32. Shah AA, McCulloch PC, Lowe WR. Failure rate of Achilles tendon allograft in primary anterior cruciate ligament reconstruction. *Arthroscopy.* 2010;26(5):667-674.
33. Shybut TB, Pahk B, Hall G, et al. Functional outcomes of anterior cruciate ligament reconstruction with tibialis anterior allograft. *Bull Hosp Jt Dis.* 2013;71(2):138-143.
34. Siebold R, Buelow JU, Bös L, Ellermann A. Primary ACL reconstruction with fresh-frozen patellar versus Achilles tendon allografts. *Int Arch Orthop Surg.* 2003;123(4):180-185.
35. Sikka RS, Narvy SJ, Vangsness CT Jr. Anterior cruciate ligament allograft surgery: underreporting of graft source, graft processing, and donor age. *Am J Sports Med.* 2011;39(3):649-655.
36. Singhal MC, Gardiner JR, Johnson DL. Failure of primary anterior cruciate ligament surgery using anterior tibialis allograft. *Arthroscopy.* 2007;23(5):469-475.
37. Snow M, Campbell G, Adlington J, Stanish WD. Two to five year results of primary ACL reconstruction using doubled tibialis anterior allograft. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(10):1374-1378.
38. Sun K, Tian S, Zhang J, et al. Anterior cruciate ligament reconstruction with BPTB autograft, irradiated versus non-irradiated allograft: a prospective randomized clinical study. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(5):464-474.
39. Sun K, Tian SQ, Zhang JH, et al. Anterior cruciate ligament reconstruction with bone–patellar tendon–bone autograft versus allograft. *Arthroscopy.* 2009;25(7):750-759.
40. Sun K, Zhang J, Wang Y, et al. A prospective randomized comparison of irradiated and non-irradiated hamstring tendon allograft for ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(1):187-194.
41. Sun K, Zhang J, Wang Y, et al. Arthroscopic reconstruction of the anterior cruciate ligament with hamstring tendon autograft and fresh-frozen allograft: a prospective, randomized controlled study. *Am J Sports Med.* 2011;39(7):1430-1438.
42. Tisherman R, Wilson K, Horvath A, et al. Allograft for knee ligament surgery: an American perspective. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(6):1882-1890.
43. Verhagen AP, de Vet HC, de Bie RA, et al. The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. *J Clin Epidemiol.* 1998;51(12):1235-1241.
44. Viechtbauer W. Conducting meta-analyses in R with the metafor package. *J Stat Soft.* 2010;36(3):1-48.
45. Wang F, Kang HJ, Chen BC, Zhang YZ, Su YL. Primary ACL reconstruction: comparison of Achilles tendon allograft with tibial anatomical fixation and patellar tendon allograft with external aperture fixation. *Eur J Orthop Surg Traumatol.* 2011;21(5):333-339.
46. 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.