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Long-Term Outcomes in Anterior Cruciate Ligament Reconstruction

A Systematic Review of Patellar Tendon Versus Hamstring Autografts

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Background: Much controversy still exists surrounding graft choice in anterior cruciate ligament (ACL) reconstruction. Over the past decade, an increase in comparative studies with longer follow-up has enhanced our understanding of current graft options and outcomes.

Purpose: To describe the long-term comparative outcomes of ACL reconstruction with autograft bone–patellar tendon–bone (BPTB) versus autograft hamstring (HS) ACL reconstruction with regard to clinical and radiographic outcomes.

Study Design: Systematic review; Level of evidence, 2.

Methods: A search of the PubMed, MEDLINE, Cochrane, and Scopus databases was performed to identify studies in the English language with outcome data comparing ACL reconstruction utilizing autograft BPTB and autograft HS; only studies with a minimum 5-year follow-up were included. Outcome data included failure and complications, manual and instrumented laxity, patient-reported outcomes, and radiographic risk of osteoarthritis.

Results: Twelve studies with a total of 953 patients met the inclusion criteria. Of these studies, 8 were level 1 evidence and 2 were level 2. Mean follow-up was 8.96 years (range, 5-15.3 years). No differences in graft failure or manual or instrumented laxity were seen in any studies. Lower clinical outcomes scores and greater motion loss were seen in BPTB patients in 1 and 2 studies, respectively. Two of 4 studies reporting on anterior knee pain, and 3 of 7 that recorded kneeling pain found it more frequently among BPTB patients. One study found significantly increased reoperation rates in HS patients, while another found a similar result in BPTB, and 1 study reported a significant increase in contralateral ACL tears in BPTB patients. Three of 5 studies reporting on radiographic evidence of osteoarthritis noted significantly increased rates in BPTB patients.

Conclusion: This systematic review comparing long-term outcomes after ACL reconstruction with either autograft BPTB or autograft HS suggests no significant differences in manual/instrumented laxity and graft failures between graft types. An increase in long-term anterior knee pain, kneeling pain, and higher rates of osteoarthritis were noted with BPTB graft use.

Keywords: ACL reconstruction; long-term; osteoarthritis; autograft; review

Anterior cruciate ligament (ACL) injury is a common occurrence, especially among young athletes. ACL reconstruction is therefore one of the most common orthopaedic procedures performed.[16] Restoring knee stability is thought to benefit not only in the short term with knee stabilization and patient return to sport but also in the long term due to the purported increased risk of subsequent chondral or meniscal damage in the unstable knee.[3] While this surgical procedure is generally accepted, there are a variety of specific techniques that remain widely debated. Perhaps most controversial is the question of graft choice, particularly in autograft reconstruction, where donor site morbidity and

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long-term outcome is a concern. Two of the most common autografts used are bone–patellar tendon–bone (BPTB) and quadrupled hamstring (HS).[3] Although numerous studies have been performed comparing these graft types, most focus on short-term outcomes with follow-up of 2 years or less, and thereby lack substantive evidence favoring one technique over another.[20]

In 2011, Magnussen et al[11] published the first and only systematic review on the topic with a minimum of 5 years of follow-up data. With the importance of evidence-based medicine on the rise in the past 20 years, an increasing number of studies with intermediate- and long-term follow-up have subsequently been published. A review of this more recent literature with longer follow-up may provide surgeons with a valuable tool in the decision-making process and may aid in discussions with patients regarding long-term clinical outcome and morbidity.

The purpose of this study was to conduct a systematic review of the current literature comparing BPTB autograft versus HS autograft for ACL reconstruction, with a minimum of 5-year follow-up. We sought to compare long-term outcomes with regard to knee stability or graft failure, complications, functional outcome, and radiographic evidence of osteoarthritis (OA). Our null hypothesis was that there is no difference between these 2 autograft types for ACL reconstruction.

METHODS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed from the inception of the study. A literature search of 4 databases (PubMed, MEDLINE, Cochrane, and Scopus) was performed from inception through January 2016. Key search terms included "ACL," "anterior cruciate ligament," "reconstructive surgical procedures," "patellar tendon," "hamstring," "gracilis," "semitendinosus," "autologous," and "long term" in different iterations. Included were comparative studies on BPTB autograft versus single-bundle HS autograft, level 1 and 2 evidence according to the *Journal of Bone and Joint Surgery–American Volume* grading system,[18] and minimum 5-year follow-up. Excluded were non-English articles; allograft, in vitro, animal, or cadaveric studies; and systematic reviews and meta-analyses. When multiple studies existed utilizing the same patient population but reporting outcomes at different time points, the study with the longest follow-up was included in our review while the rest were excluded.

Data Extraction

A "Relevant Information Sought to Be Extracted From Individual Trials" list was used as a baseline template for data collection.[4] All items in the PRISMA 2009 checklist for systematic reviews were included.[14] Extracted data included study details (journal, study design, level of evidence, etc), key study statements, patient demographics (age, sex, etc), length of clinical follow-up, percentage lost to follow-up, description of surgical technique, associated meniscal/chondral/ligamentous injury seen during surgery, rehabilitation protocol, clinical outcome assessments (range of motion, anterior drawer test, pivot-shift test, Lachman test, and knee laxity measurements with KT-1000/KT-2000 arthrometer), objective functional testing (1-leg hop, stair hop, and agility tests), isokinetic muscle strength testing, patient-reported quantitative outcome measures (International Documentation Knee Documentation Committee [IKDC] grade, Lysholm score, Tegner activity scale, etc), radiographic evidence of OA, graft failures and associated complications, and qualitative study assessments as defined by the modified Coleman methodology score.[2] Two authors independently performed all data extraction.

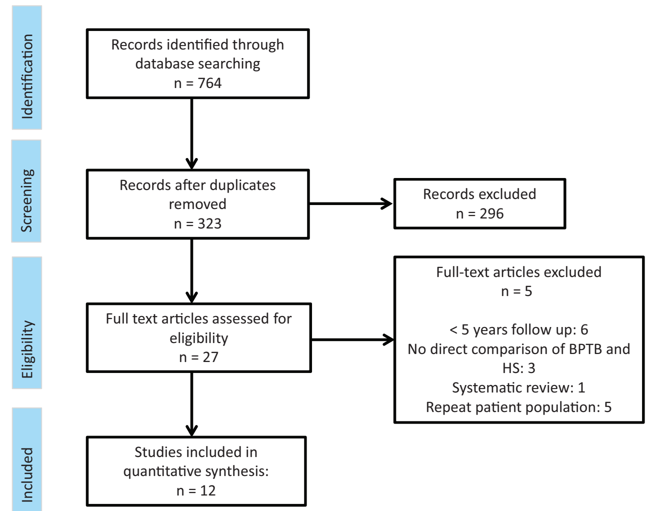

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram describing the inclusion process for studies in the systematic review.

RESULTS

Study Characteristics

An initial literature search of PubMed, MEDLINE, Cochrane, and Scopus yielded 364, 175, 11, and 214 results, respectively, for a total of 764 articles. All duplicate publications were excluded for a total of 323 unique articles. Based on our exclusion criteria, 296 articles were removed, and the remaining 27 abstracts were further filtered on review of the full-text article. Fifteen articles were further excluded: 6 for having <5-year follow-up, 3 for having no direct comparison of BPTB versus HS tendon ACL reconstruction outcomes, 5 for reporting outcomes at different time points with the same patient population, and 1 for being a systematic review. The remaining 12 publications fulfilled all criteria and were included in this systematic review[§] (Figure 1).

[§]References 1, 3, 5-8, 10, 17, 19, 21, 22, 24.

All studies had a minimum of 5 years of follow-up data. Follow-up ranged from 5 to 15.3 years (mean: 8.96 years). Clinical follow-up was reported in all 12 studies, with follow-up rates ranging from 34% to 100%. Radiographic data were reported at final follow-up in 5 studies. Four of the studies excluded patients with concomitant chondral or meniscal pathology.[3,8,22,24] Of the remaining studies, only 1 reported a statistically significant difference in concomitant pathology between the 2 groups; Sajovic et al[19] showed significant increase in the rate of subtotal meniscectomy at the time of ACL reconstruction in the HS group.

Modified Coleman scores were calculated for each study, which were graded from 0 to 90 based on a number of criteria, including study size, randomization, outcome criteria and reporting, and subject selection.[2] Coleman methodology scores for the included studies ranged from 76 to 81 (Table 1).

Surgical Technique

All 12 studies included procedures performed by a single surgeon. Table 2 details the surgical techniques used for each, including whether they were performed transtibially or via an anteromedial portal. For BPTB procedures, nearly all studies used interference screw fixation for both tibial and femoral bone plugs, although most did not delineate whether these were metal, biocomposite, or bioabsorbable. Only 1 study used press fit, uninstrumented fixation for their femoral bone plugs, and sutures passed through an adjacent bone tunnel for their tibial fixation.[22] HS fixation was slightly more variable, with femoral tunnels relying on interference screws in 5 studies,[1,7,8,10,19] suspensory fixation in 4 studies,[5,6,21,24] and staples to the lateral femoral condyle, crosspins, and "bottleneck effect into the femoral tunnel" in 2 studies.[3,22] The tibial fixation of HS grafts included interference screws in 6 studies[1,5,7,8,10,19] and washer/screw, staples, and "sutures through an adjacent bone bridge" in all others (6/12).[3,6,17,21,22,24]

Manual and Instrumented Laxity

Eight studies reported the results of the Lachman test at most recent follow-up,[1,3,6-8,10,19,24] and 5 reported on the pivot-shift test (Table 3).[3,6,8,19,24] No significant difference in manual laxity was detected between the 2 groups among any study. Instrumented laxity testing was reported in 9 studies[1,3,5,7,10,19,21,22,24] as mean side-to-side difference at maximum follow-up using maximum manual tension with either the KT-1000 or KT-2000 arthrometer (MEDmetric). No study demonstrated any difference between the BPTB and HS groups (Table 4).

Clinical Outcomes

A combination of IKDC scores, patient-reported Lysholm scores, and/or Tegner activity scores were reported in 10 of the 12 studies.[‖] IKDC results were reported as normal (A), nearly normal (B), abnormal (C), and severely abnormal (D). One study noted significantly better IKDC scores in the HS group[22] (Table 5). The remainder of the studies showed no significant difference in reported clinical outcomes between BPTB and HS grafts.

[‖]References 1, 5, 6, 8, 10, 17, 19, 21, 22, 24.

Complications

Table 6 details the complications encountered in each group, as well as the number of contralateral graft tears at the time of most recent follow-up. The most common causes for reoperation were meniscal and cartilage debridement. One study showed a significant increase in reoperation for a number of reasons—including ACL revisions and subsequent chondral and meniscal pathology—in HS patients.[3] Leys et al[8] reported a significant increase in contralateral ACL tears with BPTB graft.

Seven studies reported on the presence of kneeling pain[5,8,10,19,21,22,24] and 4 reported on anterior knee pain.[6,19,21,24] Of those, 3 noted a statistically significant increase in kneeling pain in BPTB,[5,8,22] and 2 noted a significant increase in anterior knee pain among BPTB patients[6,24] (Table 7). Finally, 2 studies noted a significant isolated motion loss with BPTB.[6,17]

Radiographic Outcomes: Osteoarthritis

Weightbearing anteroposterior, lateral, and posteroanterior views at 30° of flexion were obtained at most recent follow-up and used to determine severity of OA in 5 of the 12 studies.[6-8,19,21] Of those, 2 studies reported OA utilizing the IKDC grading system for joint space narrowing (A, normal; B, minimal; C, narrowing up to 50%; D, narrowing greater than 50%).[8,19] One study used the Kellgren-Lawrence classification,[21] and 2 others used surgeon-reported descriptions of OA (mild, moderate, or severe).[6,7] In all, 3 studies found a significant increase in OA in the BPTB patients, as defined by IKDC grade B or greater, or "moderate to severe" joint space narrowing (Table 8).[7,8,19] No studies showed an increased risk of OA with HS grafts. None of the studies commented on the presence of tunnel widening.

Failures

Failure was described as graft rupture, with other reasons for reoperation categorized as "complications." All but 1 study reported the presence or absence of graft failures.[1] All studies stated that failures were excluded from further analysis. Three studies reported zero failures.[6,7,24] Table 9 details the number of failures per study and causes of failure, if reported. No studies showed any statistically significant difference in the rates of graft failure between the 2 groups.

DISCUSSION

A tremendous body of literature has explored the factors influencing outcome after ACL reconstruction, including

TABLE 1
Overview of Included Studies[a]

Authors	Year	Journal	Procedure Date Range	Level of Evidence	No. of Patients at Most Recent Follow-up	Study Design	Single or Multicenter	Country	Mean Length of Follow-up (Range)	% Follow-up	Coleman Score	Male/Female (Male %)	Age, y, Mean (Range)
Gifstad et al[3]	2013	*KSSTA*	2001-2004	1	93	RCT	Multicenter	Norway	7 y (63-94 mo)	90	81	72/42 (63%)	27 (18-49)
Holm et al[5]	2010	*AJSM*		1	57	RCT	Single	Norway	10 y	34	81	33/24 (45%)	26 (15-50)
Ibrahim et al[6]	2005	*Arthroscopy*	1994-1996	1	85	RCT	Single	Kuwait	6.75 y (60-96 mo)	100	78	85/0 (100%)	22.3 (17-34)
Keays et al[7]	2007	*AJSM*		2	56	Cohort	Single	Australia	6 y	90	76	39/17 (70%)	27
Lidén et al[10]	2007	*AJSM*	1995-1997	1	68	RCT	Single	Sweden	7 y (68-114 mo)	96	78	49/22 (69%)	BPTB: 28 (14-49), HS: 29 (15-59)
Ahldén et al[1]	2009	*KSSTA*	1995-1998	2	47	RS	Single	Sweden	BPTB: 89 mo (77-110 mo), HS: 86 mo (69-109 mo)	51	76	32/15 (68%)	BPTB: 26 (14-48), HS: 29 (15-40)
O'Neill[17]	2001	*JBJS-A*	1989-1994	1	225	RCT	Single	United States	8.5 y (6-11 y)	100	78	NR	NR
Leys et al[8]	2012	*AJSM*	1993-1994	2	94	Cohort	Single	Australia	15 y	87	81	95/85 (52%)[b]	BPTB: 25 (15-42), HS: 24 (13-52)
Sajovic et al[19]	2011	*AJSM*	1999-2000	2	52	RCT	Single	Slovenia	11 y	82	78	30/22 (46%)	BPTB: 38 (27-58), HS: 36 (25-54)
Webster et al[21]	2016	*AJSM*	1996-1998	1	47	RCT	Single	Australia	15.3 y (14-17)	72	86	36/11 (77%)	BPTB: 26.6, HS: 26.1
Wipfler et al[22]	2011	*Arthroscopy*	1998-1999	1	54	RCT	Single	Germany	8.8 y (7.41-10 y)	87	78	37/25 (59%)	BPTB: 29.87 (25-55), HS: 34.23 (26-64)
Zaffagnini et al[24]	2006	*KSSTA*	1998	1	75	RS	Single	Italy	5 y	100	81	34/26 (56%)	29.5 (15-49)

[a]*AJSM*, *American Journal of Sports Medicine*; BPTB, bone–patellar tendon–bone; HS, hamstring; *JBJS-A*, *Journal of Bone and Joint Surgery, American Volume*; *KSSTA*, *Knee Surgery, Sports Traumatology, Arthroscopy*; NR, not reported; RCT, randomized controlled trial; RS, randomized series.

[b]Results reported at time of selection not most recent follow-up.

TABLE 2
Overview of Surgical Details for Included Studies[a]

					BPTB		HS	
Authors	No. of Surgeons	No. of BPTB (%)	No. of HS	Surgical Technique	Femoral Fixation	Tibial Fixation	Femoral Fixation	Tibial Fixation
Gifstad et al[3]	NR	58 (51)	56	TT	IFS	IFS	Crosspin	Washer/Screw
Holm et al[5]	1	35 (48)	37	TT	IFS	IFS	END	IFS
Ibrahim et al[6]	1	40 (47)	45	TT	IFS	IFS	END	Washer/Screw
Keays et al[7]	1	31 (50)	31	TT	IFS	IFS	IFS	IFS
Lidén et al[10]	1	34 (48)	37	TT	IFS	IFS	IFS	IFS
Ahldén et al[1]	1	22 (47)	25	TT	IFS	IFS	IFS	IFS
O'Neill[17]	NR	NR	NR	Group 1: 2-incision HS Group 2: 2-incision BPTB Group 3: 1-incision BPTB	NR	NR	NR	NR
Leys et al[8]	1	90 (50)	90	AM	IFS	IFS	IFS	IFS
Sajovic et al[19]	1	32 (50)	32	AM	IFS	IFS	IFS	IFS
Webster et al[21]	1	31 (48)	34	TT	END	IFS	END	Screw
Wipfler et al[22]	1	31 (50)	31	AM	Press fit	Adjacent bone tunnel	Bottleneck effect in tunnel	Adjacent bone bridge
Zaffagnini et al[24]	1	50 (50)	50	TT	IFS	IFS	Group II: END Group III: Staples to LFC	Group II: IFS Group III: Staple

[a]AM, anteromedial; BPTB, bone–patellar tendon–bone; END, Endobutton fixation; HS, hamstring; IFS, interference screw fixation; LFC, lateral femoral condyle; NR, not reported; TT, transtibial.

TABLE 3
Manual Laxity[a]

Authors	BPTB No. of Patients at Follow-up	BPTB Lachman Grade 0-1	BPTB Lachman Grade 2-3	BPTB Pivot Grade 0-1	BPTB Pivot Grade 2-3	Hamstring No. of Patients at Follow-up	Hamstring Lachman Grade 0-1	Hamstring Lachman Grade 2-3	Hamstring Pivot Grade 0-1	Hamstring Pivot Grade 2-3	Significance
Gifstad et al[3]	45	97.8 (44)	2.3 (1)	97.8 (44)	2.3 (1)	48	97.9 (47)	2.1 (1)	97.9 (47)	2.1 (1)	ns
Ibrahim et al[6]	40	87.5 (35)	14.3 (5)	87.5 (35)	14.3 (5)	45	86.7 (39)	17.9 (7)	82.2 (37)	17.8 (8)	ns
Keays et al[7]	29	100 (29)	0 (0)	NR	NR	27	100 (27)	0 (0)	NR	NR	ns
Lidén et al[10]	30	96.7 (29)	3.4 (1)	NR	NR	32	93.8 (30)	6.7 (2)	NR	NR	ns
Ahldén et al[1]	21	100 (21)	0 (0)	NR	NR	23	91.3 (21)	9.5 (2)	NR	NR	ns
Leys et al[8]	43	100 (43)	0 (0)	100 (43)	0 (0)	51	100 (51)	0 (0)	100 (51)	0 (0)	ns
Sajovic et al[19]	25	96 (24)	4.2 (1)	100 (25)	0 (0)	27	100 (27)	0 (0)	100 (27)	0 (0)	ns
Zaffagnini et al[24]	25	100 (25)	0 (0)	100 (25)	0 (0)	50	96 (48)	4.2 (2)	92 (46)	8 (4)	ns

[a]Lachman and pivot-shift results are reported as % (n). BPTB, bone–patellar tendon–bone; NR, not reported; ns, not significant.

TABLE 4
Instrumented Laxity[a]

Authors	Side-to-Side Difference BPTB, mm	Side-to-Side Difference HS, mm	Significance
Gifstad et al[3]	1.4 ± 1.8	1.4 ± 1.4	ns
Holm et al[5]	3.0 ± 3.2	2.0 ± 3.5	ns
Keays et al[7]	1.36 ± 1	1.3 ± 1.4	ns
Lidén et al[10]	2.3	2.7	ns
Ahldén et al[1]	1.4 ± 2.6	2.6 ± 3.3	ns
Sajovic et al[19]	2.5 ± 1.7	1.5 ± 2	ns
Webster et al[21]	0.6 ± 1.5	1.2 ± 1.3	ns
Wipfler et al[22]	0.90 ± 0.271	0.64 ± 0.356	ns
Zaffagnini et al[24]	0.4 ± 0.6	1.1 ± 1.9	ns

[a]Results are reported as mean ± SD. BPTB, bone–patellar tendon–bone; HS, hamstring; ns, not significant.

comparisons of tunnel placement, fixation technique, and graft choice. While a number of studies purport the superiority of one particular ACL autograft choice over another, confounding variables of such a complex surgery are often difficult to control, and may influence results. Our systematic review of level 1 and 2 studies published over the past decade focused exclusively on the direct comparison of BPTB autograft and HS autograft. While we found no difference between BPTB and HS methods in terms of clinical outcome scores, laxity, or graft failures, our study shows that there may be long-term outcome differences between patellar tendon and HS autografts, particularly in terms of risk of anterior knee pain and future OA.

There was no difference in manual or instrumented laxity in any of the studies we reviewed, contradicting the findings of more recent reviews of short-term-outcome studies. Xie et al[23] recently published a meta-analysis of 22 level 1 and 2 studies with minimum 2-year follow-up, investigating BPTB versus quadrupled HS autograft ACL reconstruction. They found a decrease in pivot and rotational instability with BPTB. This echoed the findings of Li et al,[9] who reported the results of their meta-analysis of 9 randomized controlled trials comparing BPTB and HS autograft reconstruction and found that BPTB portended an increased risk for a positive pivot shift. Finally, pooled data from a 2011 Cochrane Database systematic review of ACL reconstruction using BPTB versus HS autograft suggested that BPTB was actually protective against a positive pivot shift, but led to increased loss of extension and extension strength.[15]

Studies reporting on anterior knee pain and kneeling pain found a significantly higher risk in BPTB patients. This is consistent with previous reports of anterior knee and kneeling pain in shorter term follow-up studies and suggests that this trend may not decrease with time from surgery.[9,15,23] Therefore, patients who are candidates for ACL reconstruction with BPTB should be counseled regarding this potential risk, and perhaps this graft should be avoided in patients who are prone to anterior knee/kneeling pain, such as athletes and workers who squat or kneel repetitively. Other complications of surgery were also found to be statistically more common with BPTB autografts compared with HS. These included rates of subsequent reoperation for meniscal or chondral lesions, contralateral ACL tears, lower clinical outcomes scores, and motion loss.

The risk of OA was significantly higher in BPTB patients in the majority of studies reporting radiographic outcomes. This may be explained by the longer follow-up window of our studies, which mandates that index surgeries occurred utilizing techniques that may now have been succeeded by more modern anatomic drilling methods, thereby influencing future outcome. Indeed, only 1 study looked at tunnel positioning at the time of most recent follow-up, thereby introducing surgical technique as a potential confounding variable in the remaining studies. Future studies will determine what percentage of OA risk, if any, is mitigated by the effects of more anatomic ACL reconstruction.

Finally, we found no difference between BPTB and HS grafts with regard to graft failure in any of the studies reviewed. This contradicts the results of several recent

TABLE 5
Clinical Outcomes[a]

Authors	Overall IKDC BPTB	Overall IKDC HS	Significance	Lysholm BPTB	Lysholm HS	Significance	Tegner BPTB	Tegner HS	Significance
Holm et al[5]	NR	NR	NR	84.2 ± 15.4	86.1 ± 15.1	ns	4.3 ± 2.2	4.8 ± 2.3	ns
Ibrahim et al[6]	25 (62.5%) A, 10 (25%) B, 5 (12.5%) C, 0 D	28 (62.5%) A, 10 (22%) B, 7 (15.5%) C, 0 D	NR	91.6	92.7	NR	7.9	7.8	NR
Lidén et al[10]	Normal or nearly normal: 48% Abnormal or severely abnormal: 52%	Normal or nearly normal: 50% Abnormal or severely abnormal: 50%	ns	81	90	ns	5	6	ns
Ahldén et al[1]	NR	NR	NR	81	89	ns	5	5	ns
O'Neill[17]	Group II: 71% (53) A, 24% (18) B, 3% (2) C, 3% (2) D Group III: 73% (55) A, 20% (15) B, 4% (3) C, 3% (2) D	64% (48) A, 25% (19) B, 4% (3) C, 7%(5) D	ns	NR	NR	NR	NR	NR	NR
Leys et al[8]	47% (n = 20) A, 54% (n = 23) B, 0% C, 0% D	57% (n = 29) A, 41% (n = 21) B, 2% (n = 1) C, 0% D	ns	89	93	ns	NR	NR	NR
Sajovic et al[19]	8 (32%) A, 16 (64%) B, 1 (4%) C, 0 D	16 (59%) A, 11 (41%) B, 0 C, 0 D	ns	94	95	ns	NR	NR	NR
Webster et al[21]	88.1 ± 12.3	84.4 ± 13.5	ns	NR	NR	NR	NR	NR	NR
Wipfler et al[22]	(score 1-4: 1 = normal, 2 = nearly normal, 3 = abnormal, 4 = severely abnormal) mean (±SEM) 2.08 (±0.099); 84% A or B	Mean (±SEM) 1.5 (±0.127), 94.4% A or B	$P < .001$	87.28 ± 1.761	91.82 ± 1.713	ns	6.20 ± 0.346	6.14 ± 0.368	ns
Zaffagnini et al[24,b]	Group I: 76% A + B	Group II: 72% A + B Group III: 84% A + B	ns	NR	NR	NR	7.8 ± 1.7	Group II: 7.1 ± 1.3 Group III: 8.5 ± 1.9	ns

[a]BPTB, bone–patellar tendon–bone; HS, hamstring; IKDC, International Knee Documentation Committee; NR, not reported; ns, not significant.
[b]Zaffagnini showed double-bundle HS group had significantly faster sport resumption ($P = .0052$) than bone–patellar tendon–bone group.

database studies suggesting higher failure rates in HS autografts. Maletis et al[13] looked at 17,436 ACL reconstructions from the Kaiser Permanente registry and found that, after adjusting for covariates, factors associated with the highest risk of rerupture included allograft or HS autograft. A similar study of the same registry assessed factors associated with the need for revision ACL reconstruction in approximately 21,000 patients, stratified by age group. These authors found that autograft ACL with HS was associated with higher risk of rerupture only in those patients younger than 21 years.[12] Our level 1 and 2 studies may have been subject to type II error due to their smaller number of patients, accounting for the lack of significant difference detected. Recent meta-analyses of similar-sized studies have shown no difference in failure rates between soft tissue and BPTB autografts at a minimum of 2 years of follow-up.[9,23]

This study has several strengths. We included only studies directly comparing BPTB and HS grafts, thereby minimizing any bias in the comparison of graft choices. In addition, we reviewed only high-quality, level 1 and 2 comparative studies (as evidenced by the average Coleman methodology score of 79), thereby eliminating the bias associated with a case-series comparison, which may not have controlled for differences in patient characteristics. This study therefore summarized the best available data on long-term outcomes comparing the 2 graft choices and found several consistent, significant differences. We chose to present the results as a systematic review rather than combine the results in the form of a meta-analysis. We chose this method due to the heterogeneity of populations among individual studies, as well as differences in the reporting of outcomes. In addition, all studies involved a single surgeon performing both operations, all but 1 BPTB and 6 HS used interference screw fixation, and each study utilized the same approach for both grafts, thereby minimizing the potential influence of surgical technique.

We chose to include both level 1 and level 2 studies in order to have a more comprehensive list of studies comparing long-term outcome of BPTB and HS autografts. Since we did not combine the studies in the form of a meta-analysis, we did not feel that this inclusion criteria in any way compromised the presentation of the data for the reader. We believe it allows the reader to evaluate the results according to both levels of evidence. Accordingly, no sensitivity analysis was performed, since that would be more relevant for a meta-analysis in which pooled results are analyzed.

Several limitations also exist. A great variety of concomitant pathology was encountered at the time of index surgery, and the reporting and inclusion of this information

TABLE 6
Complications[a]

	BPTB			HS						
Authors	No. of Patients at Follow-up	Complications, % (n)	Description of Complications	No. of Patients at Follow-up	Complications, % (n)	Description of Complications	Significance	BPTB Contralateral ACL	HS Contralateral ACL	Significance
Gifstad et al[3,b]	45	17.8 (8)	6 meniscus surgeries, 1 notchplasty, 1 irrigation and debridement	48	33.3 (16)	9 meniscus surgeries, 3 debridements, 1 synovectomy, 1 cartilage surgery, 2 other surgeries	$P = .048$	1	3	ns
Holm et al[5]	29	55.2 (16)	16 meniscal surgeries	28	42.9 (12)	12 meniscus surgeries	NR	3	4	NR
Ibrahim et al[6]	40	15 (6)	3 meniscal injuries, 1 PCL rupture, 2 loose bodies	45	11.1 (5)	3 meniscal injuries, 2 loose bodies	ns	2	3	ns
Keays et al[7,c]	29	20.7 (6)	1 ipsilateral PCL rupture, 2 meniscal injuries, 1 asymptomatic calcification in PT, 1 loose body, 1 hemangioma in vastus medialis	27	14.8 (4)	3 meniscus surgeries, 1 loose body removal		2 (excluded from analysis)	3	NR
Lidén et al[10,d]	32	25 (8)	1 culture negative effusion, 3 meniscus injuries, 3 symptomatic screws, 1 other	36	16.7 (6)	1 septic arthritis, 1 meniscus tear, 1 symptomatic screw, 3 other	ns	NR	NR	
O'Neill[17]	150		NR	75		NR		NR	NR	NR
Leys et al[8]	43	25.6 (11)	5 meniscectomies, 2 excisions of tibial screw, 1 excision of patellar tendon cyst, 1 excision of cyclops lesion, 2 arthroscopies	51	27.5 (14)	10 meniscectomies, 1 excision of tibial ganglion, 2 excisions of cyclops lesion, 1 ORIF of tibial fracture	ns	23 (26%)	11 (12%)	$P = .02$
Sajovic et al[19,20,e,f]	25	0 (0)	NR	27	7.4 (2)	2 meniscus surgeries	NR	3 (9%) (excluded from analysis)	2 (6%) (excluded from analysis)	ns
Webster et al[21,g]	22		NR	25		NR	NR	4 (18%) (excluded from ROM and laxity analysis)	2 (8%) (excluded from ROM and laxity analysis)	NR
Wipfler et al[22]	28		NR	25		NR		NR	NR	NR
Zaffagnini et al[24]	25	0 (0)	NR	50	0 (0)	NR		0	0	NR

[a]ACL, anterior cruciate ligament; BPTB, bone–patellar tendon–bone; HS, hamstring; ORIF, open reduction internal fixation; NR, not reported; ns, not significant; PCL, posterior cruciate ligament; PT, patellar tendon; ROM, range of motion.

[b]The Gifstad trial calculated a *P* value for subsequent knee surgery, rather than complications. Subsequent knee surgery thus included revision ACL reconstruction.

[c]The Keays trial had a significant ($P < .001$) increase in tibiofemoral arthritis in the BPTB group as compared with the HS tendon group.

[d]The Lidén complication rate that was not statistically significant referred only to meniscus surgeries.

[e]The Sajovic 5-year follow-up noted that there was no significant difference in overall complications; however, "In this study, significantly more subtotal meniscal resections were performed in the *hamstring* tendon group ($P = .027$); however, at 5-year follow-up, radiographic evidence of knee joint osteoarthritis was significantly elevated in patients from the patellar tendon group ($P = .012$)."

[f]The Sajovic 11-year follow-up noted that "Grade B and C abnormal radiographic findings were seen in 84% (21 of 25) of patients in the PT group and in 63% (17 of 27) of patients in the STG group ($P = .008$)."

[g]The Webster trial reported that a "higher proportion of patients in the PT group were participating in sport on a weekly basis (73% PT, 48% HS; $P = .05$). There was no difference in the degree of osteoarthritis between the groups."

varied widely by study. This could certainly affect outcomes, particularly reoperation rates and subsequent joint space loss. Also, there was not enough consistency in the description of surgical technique in the included studies to allow detailed reporting on whether or not bone grafting was performed in BPTB patients, with only 3 of the studies including thorough or detailed surgical techniques. This could certainly affect outcomes such as anterior knee and kneeling pain. In addition, these studies did not uniformly address patient activity level or sport; nor did they address return to sport or preinjury activity level with any consistency, although these factors are known to influence retear rates in the literature.

Each individual series was also limited by the number of patients and rates of follow-up, both of which could affect the significance of the individual results. Finally, each study included a wide distribution of patient demographics, limiting the ability to comment on the effect of age or sex in the long-term outcomes of ACL reconstruction.

Ultimately, the definition of a "successful outcome" continues to flux and strongly depends on the time frame of reference. Some short-term studies define failure as the need for revision, while longer term follow-up emphasizes the avoidance of knee OA, pain, or subsequent surgery as a marker of success. Each of these factors should be considered when counseling the patient on graft choice, and the ultimate decision should incorporate individual expectations with both short- and long-term goals.

TABLE 7
Knee Pain[a]

	BPTB			HS			
Authors	No. of Follow-up	Kneeling Pain, % (n)	Anterior Knee Pain, % (n)	No. of Follow-up	Kneeling Pain, % (n)	Anterior Knee Pain, % (n)	Significance
Holm et al[5]	29	39 (11)	NR	28	29 (8)	NR	$P < .05$
Ibrahim et al[6]	40	NR	25 (10)	45	NR	6.6 (3)	$P < .05$
Lidén et al[10]	32	48 (15)	NR	36	41 (15)	NR	ns
Leys et al[8]	43	42 (18)	NR	51	26 (13)	NR	$P = .04$
Sajovic et al[19]	25	48 (12)	[b]	27	30 (8)	[b]	ns
Webster et al[21]	22	52 (11)	38 (8)	25	41 (10)	27 (7)	ns
Wipfler et al[22]	28	Kneeling test (1-4) mean: 1.48	NR	25	Kneeling test (1-4) mean: 1.09	NR	$P = .002$
Zaffagnini et al[24]	25	72 (18)	36 (9)	50	Group II: 44 (11) Group III: 12 (3)	Group II: 12 (3) Group III: 8 (2)	$P = .0001$

[a]BPTB, bone–patellar tendon–bone; HS, hamstring; NR, not reported; ns, not significant.
[b]Results reported as "anterior knee or kneeling pain."

TABLE 8
Radiographic Outcomes (Osteoarthritis)[a]

	BPTB				HS				
Authors	No. of Patients at Follow-up	IKDC	K-L	Objective	No. of Patients at Follow-up	IKDC	K-L	Objective	Significance
Ibrahim et al[6]	40	NR		Moderate OA in 35% (14)	47	NR		Moderate OA in 23% (11)	NR
Keays et al[7]	29	NR		Mild-moderate OA in 62% (18) Moderate PF OA in 41% (12)	27	NR		Mild OA in 33% (9) Mild PF OA in 30% (8)	Non-PF OA: $P < .001$ PF OA: ns
Leys et al[8]	58	Grade A: 41% (24) Grade B: 48% (28) Grade C: 10% (6)			51	Grade A: 60% (31) Grade B: 35% (18) Grade C: 4% (2)			$P < .04$
Sajovic et al[19]	25	Grade A: 16% (4) Grade B: 40% (10) Grade C: 44% (11)			27	Grade A: 37% (10) Grade B: 52% (14) Grade C: 7% (2) Grade D: 4% (1)			$P < .008$
Webster et al[21]	19		Grade 0-1: 74% (14) Grade 2-3: 26% (5)		19		Grade 0-1: 68% (13) Grade 2-3: 32% (6)		ns

[a]BPTB, bone–patellar tendon–bone; HS, hamstring; IKDC, International Knee Documentation Committee; K-L, Kellgren-Lawrence; NR, not reported; ns; not significant; OA, osteoarthritis; PF, patellofemoral.

TABLE 9
Failures[a]

	BPTB			HS			
Authors	No. of Patients at Follow-up	No. of Failures, % (n)	Cause of Failure	No. of Patients at Follow-up	No. of Failures, % (n)	Cause of Failure	Significance
Gifstad et al[3]	45	4 (2)	NR	48	6 (3)	NR	ns
Holm et al[5]	29	10 (3)	Traumatic	28	11 (3)	Traumatic	NR
Ibrahim et al[6]	40	0 (0)	NR	45	0 (0)	NR	NR
Keays et al[7]	29	0 (0)	NR	27	4 (1)	Atraumatic	NR
Lidén et al[10]	32	3 (1)	NR	36	6 (2)	NR	NR
O'Neill[17]	150	5 (4) (group II) 7 (5) (group III)	NR	75	8 (6) (all group I)	NR	ns
Leys et al[8]	43	8 (7)	NR	51	17 (15)	NR	ns
Sajovic et al[19]	25	12 (4)	NR	27	6 (2)	NR	ns
Webster et al[21]	22	5 (1)	Traumatic	25	12 (3)	NR	ns
Wipfler et al[22]	28	11 (3)	NR	25	12 (3)	Atraumatic	NR
Zaffagnini et al[24]	25	0 (0)	NR	50	0 (0)	NR	NR

[a]BPTB, bone–patellar tendon–bone; HS, hamstring; NR, not reported; ns, not significant.

CONCLUSION

This review of recent literature comparing the long-term follow-up of ACL reconstruction with either BPTB autograft or HS autograft suggests no significant differences in manual/instrumented laxity and graft failures between graft types. BPTB grafts are associated with an increase in anterior knee and kneeling pain, and a greater frequency of OA after 5 years. As the number of high-quality, randomized controlled trials comparing ACL techniques continues to increase, the need for studies that analyze confounding variables, specifically concomitant injury, patient demographics, and demand, persists. In the interim, consistently applied surgical techniques can offer excellent outcomes, regardless of graft choice.

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