Comparison Of Graft Failure Rate Between Autografts Placed Via An Anatomic Anterior Cruciate Ligament Reconstruction Technique

By: Conrad M. Gabler, MS, ATC, Cale A. Jacobs, PhD, **Jennifer Sebert Howard, PhD, ATC**, Carl G. Mattacola, PhD, ATC, FNATA, and Darren L. Johnson, MD

Abstract

Purpose: To review the literature comparing graft failure rate between patellar and hamstring tendon autografts placed anatomically and to determine if there are differences in return to preinjury activity levels between autografts. Study Design: Systematic review with meta-analysis and meta-regression. Methods: The PubMed, MEDLINE, SPORTDiscus, and CINAHL databases were used to identify studies published from January 1, 2000, through March 7, 2014. To compare postoperative outcomes between patellar tendon and hamstring tendon autografts, summary event rates for graft failure and return to preinjury activity level were calculated. A meta-analysis was performed to cal- culate a summary odds ratio (OR) for graft failure between autografts using the studies that directly compared the 2 autografts. Meta-regression analyses were performed to assess the influence of postoperative follow-up time on graft failure rate. Results: A total of 28 studies reported graft failures for patellar tendon (6 studies) and hamstring tendon (26 studies) autografts used with anatomic ACL reconstruction; 4 of the 28 were comparison studies. Graft failure rate was not significantly different between patellar tendon (7.0% [95% CI, 4.6%-10.5%]) and hamstring tendon autografts (3.9% [95% CI, 2.7%-5.6%]). The odds of graft failure were slightly higher for hamstring tendon autografts (OR, 1.21 [95% CI, 0.63-2.33]), but this difference was not significant (P = .57). The rate of patients returning to preinjury activity levels was not significantly different between patel- lar (n = 1 study; 58.1% [95% CI, 40.4%-73.9%]) and hamstring tendon autografts (n = 5 studies; 75.6% [95% CI, 43.7%-92.5%]). Overall graft failure rate was positively associated with postoperative follow-up time, but this effect was only significant with ham- string tendon autografts (P \ .05). Conclusion: Differences in graft failure rate between patellar tendon and hamstring tendon autografts were not significant. Although follow-up time was only found to have a significant influence on hamstring tendon graft failure rates, this was likely due to the smaller sample of studies assessing patellar tendon graft failures. Differences in return to preinjury activity levels could not be determined due to the lack of studies assessing that outcome. Both patellar and hamstring tendon autografts demonstrate a low risk of failure and moderately high return to activity level after anatomic ACL reconstruction.

Gabler, C. M., et al. (2015). "Comparison of Graft Failure Rate Between Autografts Placed via an Anatomic Anterior Cruciate Ligament Reconstruction Technique: A Systematic Review, Meta-analysis, and Meta-regression." The American Journal of Sports Medicine 44(4): 1069-1079. https://doi.org/10.1177/0363546515584043. Publisher version of record available at: http://journals.sagepub.com/doi/full/10.1177/0363546515584043

Comparison of Graft Failure Rate Between Autografts Placed via an Anatomic Anterior Cruciate Ligament Reconstruction Technique

A Systematic Review, Meta-analysis, and Meta-regression

Conrad M. Gabler,*† MS, ATC, Cale A. Jacobs,‡ PhD, Jennifer Sebert Howard,§ PhD, ATC, Carl G. Mattacola,† PhD, ATC, FNATA, and Darren L. Johnson,§ MD
Investigation performed at University of Kentucky, Lexington, Kentucky, USA

Background: Recent data from the Danish anterior cruciate ligament (ACL) registry demonstrated increased reoperation rates for hamstring tendon autografts when an anatomic ACL reconstruction is performed. This is consistent with reports of greater time needed for hamstring tendon autografts to mature compared with other autografts.

Purpose: To review the literature comparing graft failure rate between patellar and hamstring tendon autografts placed anatomically and to determine if there are differences in return to preinjury activity levels between autografts.

Study Design: Systematic review with meta-analysis and meta-regression.

Methods: The PubMed, MEDLINE, SPORTDiscus, and CINAHL databases were used to identify studies published from January 1, 2000, through March 7, 2014. To compare postoperative outcomes between patellar tendon and hamstring tendon autografts, summary event rates for graft failure and return to preinjury activity level were calculated. A meta-analysis was performed to calculate a summary odds ratio (OR) for graft failure between autografts using the studies that directly compared the 2 autografts. Meta-regression analyses were performed to assess the influence of postoperative follow-up time on graft failure rate.

Results: A total of 28 studies reported graft failures for patellar tendon (6 studies) and hamstring tendon (26 studies) autografts used with anatomic ACL reconstruction; 4 of the 28 were comparison studies. Graft failure rate was not significantly different between patellar tendon (7.0% [95% CI, 4.6%-10.5%]) and hamstring tendon autografts (3.9% [95% CI, 2.7%-5.6%]). The odds of graft failure were slightly higher for hamstring tendon autografts (OR, 1.21 [95% CI, 0.63-2.33]), but this difference was not significant ($P = .57$). The rate of patients returning to preinjury activity levels was not significantly different between patellar (n = 1 study; 58.1% [95% CI, 40.4%-73.9%]) and hamstring tendon autografts (n = 5 studies; 75.6% [95% CI, 43.7%-92.5%]). Overall graft failure rate was positively associated with postoperative follow-up time, but this effect was only significant with hamstring tendon autografts ($P < .05$).

Conclusion: Differences in graft failure rate between patellar tendon and hamstring tendon autografts were not significant. Although follow-up time was only found to have a significant influence on hamstring tendon graft failure rates, this was likely due to the smaller sample of studies assessing patellar tendon graft failures. Differences in return to preinjury activity levels could not be determined due to the lack of studies assessing that outcome. Both patellar and hamstring tendon autografts demonstrate a low risk of failure and moderately high return to activity level after anatomic ACL reconstruction.

Keywords: anteromedial portal; autograft; systematic review; meta-analysis; meta-regression

Anterior cruciate ligament (ACL) injuries account for more than 50% of all knee injuries,[6] and they often become a functional limitation during activities of daily living if left untreated. Before the 21st century, transtibial ACL reconstruction (ACLR) was the primary surgical treatment for restoring joint stability, returning patients to their previous levels of activity, and reducing the risk of subsequent joint injuries. Graft placement for transtibial ACLR is performed by drilling the femoral tunnel through the tibial tunnel, making the position of the femoral tunnel largely dependent on the position of the tibial tunnel. However, this technique commonly places the graft in a more vertical position relative to the native ACL,[43,46] which has been

shown to cause residual joint instability and inferior functional outcomes.[4,5,24] Since the early 2000s, surgical techniques for ACLR have evolved to restore the anatomy of the native ACL in attempts to improve postoperative outcomes.

"Anatomic" ACLR is defined as a functional restoration of the ACL to its native dimensions, orientation, and insertion.[60] The prime distinction of anatomic ACLR involves placing the graft in the same position as the native ACL by drilling the tunnels through the tibial and femoral ACL footprints. To match the footprints of the native ACL, the tibial and femoral tunnels must be drilled independent of one another using an anteromedial drilling technique. In this technique, the position of the tibial tunnel is identical to transtibial ACLR, but instead of drilling transtibially to create the femoral tunnel, a second portal is made anteromedially (medial to the patellar tendon) to more accurately target the femoral footprint of the ACL.[42] This technique allows the graft to better reflect the anatomic position of the ACL and aims to restore its native function.

Over the past decade, anatomic ACLR has demonstrated superior outcomes compared with transtibial ACLR with regard to joint stability, return to activity, and the risk for subsequent ipsilateral knee surgery.[4,5,12,16,24,65] However, recent data from the Danish ACL registry demonstrate an increased revision rate with anatomic ACLR techniques, but when stratifying their data by autograft type, anatomically placed hamstring tendon (HT) autografts demonstrated 2 times the risk of revision (relative risk, 2.2) compared with transtibially placed HT autografts, while there were no risk differences between reconstruction techniques for patellar tendon (PT) autografts.[50] European countries primarily use HT autografts when performing ACLRs due to the negative outcomes often associated with PT autografts (ie, donor-site morbidity, loss of knee-extensor mechanism, and increased risk of developing patellofemoral disorders).[9,25,30] Conversely, HT autografts are known to lead to increased joint laxity, hamstring weakness, and slower graft-tunnel healing,[10,17,38] which may explain why a higher risk of revision was observed for HT autografts. Numerous systematic reviews and meta-analyses have been published within the past 15 years comparing postoperative outcomes between PT and HT autografts, but there is mixed evidence with regard to which autograft has the higher risk of failing. However, no publications have compared graft failure rate between these 2 autografts when placed via an anatomic ACLR technique.

The primary purpose of this study was to systematically review, synthesize, and critically appraise the literature comparing graft failure rate between PT and HT autografts when an anatomic ACLR technique is used. Our secondary purpose was to compare the rate of patients who return to their preinjury levels of activity based on the type of autograft they received for anatomic ACLR. Return to preinjury activity level (RTAL) is an important postoperative outcome because it encompasses both function and quality of life. By using both graft failure rate and RTAL rate as our outcome measures, it allows us to better delineate the success of anatomic ACLR when comparing the autografts. We hypothesized that HT autografts would demonstrate a significantly greater failure rate than PT autografts but that RTAL rate would not differ between the two.

TABLE 1
Stepwise PubMed/EBSCOhost Search Strategy[a]

Step	Strategy	PubMed	EBSCOhost
1	Search "ACL OR anterior cruciate ligament"	7578	13,108
2	Search "reconstruct*"	85,384	95,662
3	Search "anatomic OR anteromedial portal OR native"	72,627	80,587
4	Search "cadaver OR allograft"	42,881	46,756
5	Search "#1 AND #2"	4042	6848
6	Search "#5 AND #3"	588	898
7	Search "#6 NOT #4"	**358**	**580**

[a]Bolded numbers indicate the final number of articles that were searched through after the search term strategy was performed in each database.

METHODS

Review Protocol

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (www.prisma-statement.org) were used to conduct our systematic review and meta-analysis. The PRISMA checklist is available in the Appendix (available in the online version of this article at http://ajsm.sagepub.com/supplemental).

Information Sources

The databases used for the electronic search included PubMed, MEDLINE, SPORTDiscus, and CINAHL. The latter 3 databases were searched using EBSCOhost. Our search was restricted to English-language publications, human subject studies, and academic journal articles from January 1, 2000, through March 7, 2014.

Search

The search strategy is presented in Table 1. Hand-searched articles were identified through the reference lists of the articles included in the qualitative synthesis.

*Address correspondence to Conrad M. Gabler, MS, ATC, Department of Rehabilitation Sciences, Athletic Training Program, Charles T. Wethington Jr. Building, 2nd Floor, 900 South Limestone, Room 214C, Lexington, KY 40536-0200, USA (email: gabler.cm@uky.edu).
†Department of Rehabilitation Sciences, Athletic Training Program, University of Kentucky, Lexington, Kentucky, USA.
‡Department of Orthopedics & Sports Medicine, Lexington Clinic, Lexington, Kentucky, USA.
§Department of Orthopaedic Surgery & Sports Medicine, University of Kentucky, Lexington, Kentucky, USA.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

Eligibility Criteria

Only those studies providing level 3 evidence or higher (based on the Oxford Levels of Evidence[41]) were assessed in this review. For a study to be included in the qualitative synthesis, both an anatomic (or anteromedial portal) technique and autograft (PT or HT) had to be used for the ACLR. Follow-up assessments after surgery had to involve either objective ACL graft failure (retear or primary revision) confirmed via magnetic resonance imaging and/or first-look arthroscopy or subjective physical activity status with a minimal postoperative follow-up period of 24 months. We chose a cutoff of 24 months because most ACLR outcome studies include a minimum 2-year postoperative follow-up assessment. There were no restrictions on study design, but the studies had to involve human subjects who were diagnosed with a primary ACL tear (via magnetic resonance imaging or arthroscopy) and subsequently underwent anatomic ACLR. Studies were excluded if an anatomic ACLR technique was not performed, an allograft was used to reconstruct the ACL, follow-up assessments were conducted less than a mean of 24 months after surgery, or if there were no data reported on either graft failure or return to preinjury physical activity levels. Those patients who reportedly developed a Cyclops lesion were removed from the analyses.

Study Selection

The study selection process used for this systematic review consisted of 4 stages. After articles were identified through the electronic search and duplicates were removed (stage 1), their titles and abstracts were screened by one of the authors (C.M.G.) to determine if they were applicable for the purpose of the systematic review (stage 2). Once screened, the same author assessed the remaining articles for eligibility by reading through each of the methods and results sections (stage 3). Those studies deemed eligible were included in the qualitative synthesis along with the hand-searched articles (stage 4) by consensus of 2 authors (C.M.G. and C.A.J.). If the 2 authors disagreed on a decision to include or exclude an article and they could not come to a consensus, a third author (D.L.J.) was brought in to make the final decision. If studies were discovered to have shared data, only the most recent study was included.

An initial total of 938 hits were identified through PubMed and EBSCOhost (MEDLINE, SPORTDiscus, and CINAHL). After removing the duplicates between the databases, 433 articles remained. Of these 433 articles, 375 were excluded after screening their titles and abstracts. The primary reasons for excluding these articles were irrelevancy and if the outcomes mentioned in the abstract did not entail graft integrity or physical activity measures. The methods and results sections of the remaining 58 articles were then read to determine if they were eligible for inclusion. Forty of the articles were excluded because they did not use an anatomic ACLR technique, reported neither graft failure numbers nor the rate of patients who returned to preinjury activity levels, or shared data with an included study. Lastly, 10 additional articles were added to the qualitative synthesis after searching through the reference lists of the remaining 18 electronically searched articles, resulting in a total of 28 studies being included in the systematic review. Figure 1 provides a flow diagram of the search strategy used for study selection.

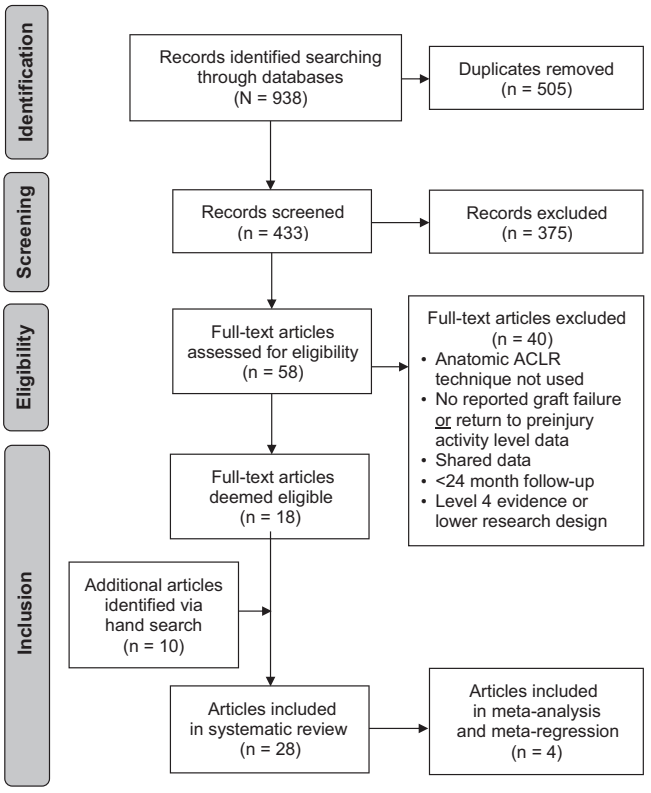

Figure 1. Search strategy used for study selection.

Data Extraction

Data extraction of the included studies was performed by one author (C.M.G.), and a second author (C.A.J.) checked the extracted data for accuracy. A spreadsheet was used for each autograft type (PT and HT) to organize and store data, including reference, study design, mean follow-up period after ACLR, sample size, type of autograft harvest, type of graft bundle used, type of graft fixation used (femoral and tibial), number of graft failures, and number of patients who returned to their preinjury activity levels.

Summary Measures

Summary event rates were analyzed using Comprehensive Meta-Analysis software (Biostat). The event rates (in percentages) for graft failure and RTAL were the primary measures of treatment effect based on autograft type used for anatomic ACLR. Graft failures were classified as retears or primary ACL revisions, and RTAL was derived from either the International Knee Documentation Committee Subjective Knee Form (question 10) or the Tegner activity scale. Summary event rates were calculated by weighing event rates from each individual study according to their sample size and variability. Summary event rates

were calculated for all data extracted from the studies and when dividing the data by autograft type (PT vs HT). By examining the 95% CIs of the summary event rates for PT and HT autografts, differences can be reported if there is overlap between the CIs of the 2 autografts.

The secondary measures included mean sample size, mean postoperative follow-up time, and mean Coleman Methodology Score (CMS) scores. We were interested in both the overall mean values from all studies included in the review and the mean values when separating the data by autograft type (PT vs HT). These secondary measures were considered useful for understanding study characteristics and interpreting the results. Differences in secondary measures between PT and HT autografts were assessed using independent sample t tests. These statistical tests were performed using SPSS version 22 (SPSS Inc), with the significance level established a priori at $P \leq .05$.

To calculate a summary odds ratio (with 95% CI) between the 2 autografts, we also performed a meta-analysis on the studies that prospectively compared graft failure data with PT and HT autografts. A forest plot was generated from the meta-analysis displaying the weighted odds ratios (ORs) of the included studies and a summary OR. Comprehensive Meta-Analysis software was used to perform these analyses. Statistical significance was defined as $P \leq .05$ (95% CI did not cross 1).

Synthesis of Results

Given the observed heterogeneity in study designs and sample sizes among the studies, random-effects DerSimonian and Laird models were used for the meta-analyses. To support the use of the random-effects model, we also conducted statistical tests of heterogeneity. The P value of the Cochran Q statistic (test for heterogeneity) was used to test the null hypothesis that event rates were the same in all studies ($P > .05$). To quantify the effect of heterogeneity in the studies' results, an I^2 statistic was also calculated ($I^2 = 100\% \times (Q - df)/Q$). The I^2 describes the percentage of total variation across studies that are due to heterogeneity instead of chance. Moderate to high values of I^2 (~50% or higher) suggest the use of a random-effects models for meta-analysis to explain the effect of heterogeneity.[21]

Meta-regression Analyses

To assess the effect of follow-up duration on both the graft failure rate and RTAL rates, respectively, we performed 2 separate meta-regression analyses. Mean postoperative follow-up duration was labeled as the continuous moderator and used as the covariate (predictor) in the regression analysis predicting the log odds of the events of interest (graft failure rate and RTAL rate). All anatomic ACLR studies included in the systematic review that provided graft failure and RTAL event rates were included in the meta-regression. If follow-up duration was found to have a significant influence (regression slope $P \leq .05$) on either graft failure rate or RTAL rate, subgroup meta-regression analyses were conducted for each autograft type (PT and HT) to determine if mean follow-up duration had a significant effect on either outcome depending on which autograft was used for anatomic ACLR. To reduce the potential effect of heterogeneity, random-effects (method of moments) models were used for the meta-regression analyses.

Publication Bias

To detect for signs of publication bias, we created a standard funnel plot by plotting the log odds of the event rate against standard error. The event rate chosen to be used for the funnel plot (graft failure or RTAL) was the event reported in most included studies.

Quality Assessment

To assess study quality, we used the CMS for each of the included studies. The CMS is a tool created to assess the methodological quality of surgical outcome studies.[11] It consists of 18 questions that assess characteristics such as study design and sample size, with a score ranging from 0 to 100 (100 representing a perfect score). The main object of the tool is to identify the influence of chance, bias, and confounding factors on the reported results. It was originally developed for the surgical management of patellar tendinopathy, but over the years, it has been modified for various orthopaedic conditions such as Achilles tendinopathy,[58] meniscectomy,[45] and articular cartilage repair.[22,39] For the purposes of this review, the CMS was used for ACLR.

RESULTS

Study Characteristics

The 28 studies provided data on a total of 2407 subjects who had previously undergone anatomic ACLR. For each study, patient characteristics were extracted and organized into tables by autograft type to allow for comparison between autograft types. Study characteristics for PT autografts and HT autografts can be seen in Tables 2 and 3, respectively. Most of the included studies (26 studies) consisted of HT autografts (2032 subjects), while only 6 studies used PT autografts (375 subjects).[14,44,48,52,62,63] Four studies[48,52,62,63] were comparative studies that examined both PT and HT autografts. All studies were either randomized clinical trials (evidence level 2) or prospective cohorts (evidence level 3).[41] Half (3/6) of the PT autograft studies were randomized clinical trials (level 2 evidence), whereas 62% (16/26) of HT autograft studies were randomized clinical trials. After data were extracted for the primary outcome measures, all 28 studies reported graft failure data, with only 5 of those studies[2,3,20,26,52] (341 subjects) reporting RTAL data. Of the 5 studies, only 1 provided RTAL data on PT autografts (31 subjects),[52] while the other 4 studies concerned HT autografts (310 subjects).[31-34]

Outcome Measures

All summary event rates are reported in Table 4. The summary graft failure rate and RTAL rate from all anatomic

TABLE 2
Characteristics of Studies Using Patellar Tendon Autografts for Anatomic Anterior Cruciate Ligament Reconstruction[a]

Study (Year)	Study Design	Mean Follow-up, mo	Sample Size, n	Harvest Type	Bundle	FemFix	TibFix	GF, n	RTAL, n
Felmet (2010)[14]	PC	123.6	154	BPTB	SB	BBPF	BBPF	6	
Otsuka et al (2003)[44]	RCT	24	20	BPTB	SB	IS	IS	0	
Pinczewski et al (2007)[48]	PC	120	82	BPTB	SB	IS	IS	7	
Sajovic et al (2011)[52]	RCT	132	31	BPTB	SB	IS	BAIS	4	18
Wagner et al (2005)[62]	PC	24	59	BPTB	SB	BAIS	BAIS	3	
Wipfler et al (2011)[63]	RCT	105.6	29	BPTB	SB	BBPF	Sutures	3	

[a]BAIS, bioabsorbable interference screws; BBPF, bone block press-fit; BPTB, bone–patellar tendon–bone; FemFix, femoral fixation; GF, graft failure; IS, metal interference screws; PC, prospective cohort; RCT, randomized clinical trial; RTAL, returned to preinjury activity level; SB, single bundle; TibFix, tibial fixation.

TABLE 3
Characteristics of Studies Using Hamstring Tendon Autografts for Anatomic Anterior Cruciate Ligament Reconstruction[a]

Study (Year)	Study Design	Mean Follow-up, mo	Sample Size, n	Harvest Type	Bundle	FemFix	TibFix	GF, n	RTAL, n
Aglietti et al (2007)[1]	PC	24	25	STG	DB	IS	IS	1	
Aglietti et al (2010)[2]	RCT	24	70	STG	SB/DB	IS	Sutures	4	43
Ahldén et al (2013)[3]	RCT	24	98	STG	SB/DB	IS	BAIS	0	22
Ferretti et al (2008)[15]	RCT	25	31	STG	SB	SWB	IS	0	
Gobbi et al (2012)[20]	RCT	36	60	ST	SB/DB	EB	BAIS	0	60
Hussein et al (2012)[23]	PC	30	94	STG	SB/DB	EB	BAIS	2	
Hussein et al (2012)[24]	RCT	51	221	STG	SB/DB	EB	BAIS	3	
Ibrahim et al (2009)[26]	RCT	29	50	STG	DB	EB	BAIS	0	47
Jagodzinski et al (2010)[27]	RCT	24	20	STG	SB	CP	IS/BBPF	1	
Jarvela et al (2008)[29]	RCT	24	70	STG	SB/DB	BAIS/IS	BAIS/IS	7	
Kondo et al (2008)[31]	PC	24	171	STG	DB	EB	Staples	1	
Kondo et al (2012)[32]	PC	24	47	STG	DB	EB	Staples	1	
Laxdal et al (2006)[33]	RCT	24	71	STG	SB	BAIS/IS	BAIS/IS	3	
Nunez et al (2012)[40]	RCT	24	52	STG	SB/DB	EB	BAIS	0	
Pinczewski et al (2007)[48]	PC	120	86	STG	SB	IS	IS	12	
Plaweski et al (2009)[49]	PC	51	105	STG	SB	EB	BAIS	4	
Sajovic et al (2011)[52]	RCT	132	32	STG	SB	IS	BAIS	2	22
Stener et al (2010)[54]	RCT	96	64	STG	SB	BAIS/IS	BAIS/IS	3	
Sun et al (2011)[55]	RCT	41.5	36	STG	SB	EB	BAIS	0	
Sun et al (2011)[56]	RCT	91.2	91	STG	SB	EB	BAIS	0	
Suomalainen et al (2013)[57]	PC	24	46	STG	SB/DB	IS	BAIS	4	
Tohyama et al (2011)[59]	PC	24	122	STG	DB	EB	Staples	0	
Wagner et al (2005)[62]	PC	24	284	STG	SB	BAIS	BAIS	16	
Wipfler et al (2011)[63]	RCT	105.6	25	STG	DB	Knotted	Sutures	3	
Yasuda et al (2006)[65]	PC	24	24	STG	DB	EB	Staples	0	
Zaffagnini et al (2008)[66]	RCT	36	37	STG	DB	Staples	Staples	0	

[a]BAIS, bioabsorbable interference screws; BBPF, bone block press-fit; CP, cross-pins; DB, double bundle; EB, endobutton; FemFix, femoral fixation; GF, graft failure; IS, metal interference screws; PC, prospective cohort; RCT, randomized clinical trial; RTAL, returned to preinjury activity level; SB, single bundle; ST, semitendinosus; STG, semitendinosus and gracilis; SWB, swing bride; TibFix, tibial fixation.

ACLR studies were 4.6% (95% CI, 3.4%-6.3%) and 71.7% (95% CI, 45.4%-88.5%), respectively. When comparing graft failure rate and RTAL rate between PT and HT autografts, no significant differences were observed (overlapping 95% CIs). The summary ORs for graft failure derived from the meta-analysis of the 4 comparative studies (see Figure 2) were not significant (1.21; 95% CI, 0.63-2.33; $P = .57$). Only 1 comparative study provided RTAL data for PT autografts.[52] Therefore, it was not possible to perform a meta-analysis to determine the odds of RTAL between autografts.

The mean (±SD) sample size of the studies included in this review was 75.2 ± 60.3 patients. There were no significant differences in mean sample size between PT (62.5 ± 50.4 patients) and HT (78.2 ± 62.9 patients) autograft data ($t(30) = -0.57$, $P = .58$). The mean follow-up time for all

TABLE 4
Summary Event Rates for Graft Failures and Return to Preinjury Activity Levels[a]

Graft	Graft Failure Rate (95% CI)	RTAL Rate (95% CI)
All	4.6 (3.4-6.3)	71.7 (45.4-88.5)
Patellar tendon	7.0 (4.6-10.5)	58.1 (40.4-73.9)
Hamstring tendon	3.9 (2.7-5.6)	75.6 (43.7-92.5)

[a]Event rates are reported in percentages. RTAL, return to preinjury activity level.

studies was 52.7 ± 40.4 months. When examining mean postoperative follow-up time between autograft types, a significant difference between PT (88.2 ± 50.5 months) and HT (44.5 ± 33.7 months) autograft data was observed ($t(30) = 2.61$, $P = .01$).

Due to graft failure being reported in all included studies, statistical tests for heterogeneity were used to determine if graft failure rates were the same in all studies. The results from the Cochran Q test rejected the null hypothesis, revealing that there was heterogeneity across the studies ($Q(31) = 56.1$, $P = .004$). Furthermore, the I^2 statistic revealed that nearly half of the total variation observed across studies was due to heterogeneity instead of chance ($I^2 = 44.7\%$). These findings justified the choice of using a random-effects model for conducting the analyses.

Meta-regression Results

The results of the meta-regression analyses can be observed in Table 5. Mean postoperative follow-up time was a significant predictor of graft failure rate after anatomic ACLR ($Z = 2.70$, $P = .007$) as revealed by the meta-regression on all 28 studies that reported graft failure data. The subgroup meta-regression analyses on autograft type revealed that follow-up time was a significant predictor for graft failure rate when HT autografts were used for anatomic ACLR ($Z = 1.99$, $P = .047$), with graft failure rates increasing as the length of follow-up time increased. This same effect did not achieve statistical significance for PT autografts ($Z = 0.84$, $P = .401$). However, the overlapping 95% CIs observed between the PT (95% CI, –0.007 to 0.018) and HT (95% CI, 0.0 to 0.02) regression slopes demonstrated no significant differences. Based on the 5 studies that reported RTAL data, follow-up time was not found to significantly predict RTAL rate after anatomic ACLR ($Z = -0.33$, $P = .74$). Due to there being only 1 study that reported RTAL data for PT autografts, there were insufficient data to perform subgroup meta-regression analyses on RTAL rate by autograft type.

Quality Assessment

The overall mean (±SD) CMS score for all 28 studies was 81.6 ± 6.8 out of a possible 100 points, indicating that the studies included in the systematic review were of moderate to high methodological quality. There were no significant differences in mean CMS scores between PT (80.2 ± 7.7) and HT (82.1 ± 6.7) autograft data ($t(30) = -0.63$, $P = .53$).

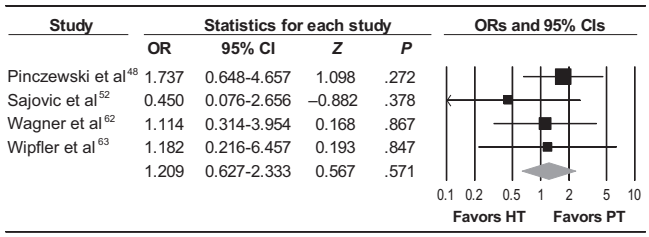

Figure 2. Forest plot of the 4 studies comparing graft failure outcomes between patellar tendon (PT) and hamstring tendon (HT) autografts. Point estimates of the weighted odds ratios for each study are represented by squares, and the 95% CIs are represented by horizontal bars. The summary odds ratio is represented by a gray diamond.

TABLE 5
Single-Variable Meta-regression Random-Effects Model Using Mean Postoperative Follow-up Time as a Predictor Variable[a]

Autograft Type (No. of Studies)	Graft Failure Rate		
	Slope (SE)	95% CI	P Value
All autografts (28 studies)	0.009 (0.003)	0.003 to 0.016	.007[b]
Patellar tendon (6 studies)	0.005 (0.007)	–0.007 to 0.018	.401
Hamstring tendon (26 studies)	0.010 (0.005)	0.000 to 0.020	.047[b]

[a]Event rates are in log odds units. SE, standard error.
[b]Statistically significant predictive effect ($P \leq .05$).

Publication Bias

Since all studies included in this review reported graft failure data, funnel plots were created by plotting the log odds of graft failure rate against the standard error. When examining the standard funnel plot (Figure 3), some asymmetry can be observed, suggesting a publication bias for graft failure data.

DISCUSSION

The purpose of this systematic review was to synthesize and critically appraise the literature comparing event rates for graft failure and RTAL between PT and HT autografts when using an anatomic ACLR technique. Graft failure rate was not significantly different between PT autografts (7.0%) and HT autografts (3.9%), with both demonstrating a low occurrence of graft failure. However, it must be considered that the mean postoperative follow-up period from the PT autograft data (88.2 months) was significantly longer than that for the HT autograft data

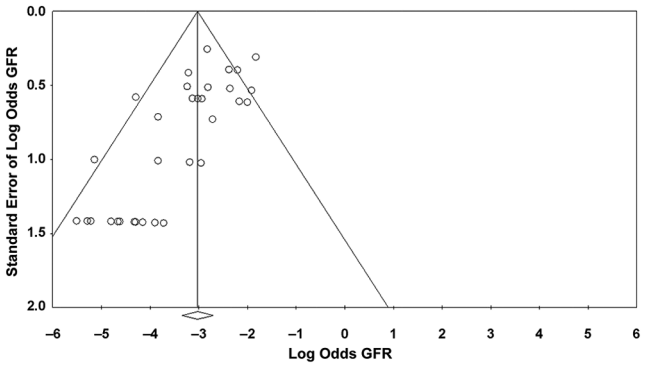

Figure 3. Funnel plot with 95% CIs about a random-effects estimate. Log Odds GFR, log odds of graft failure rate.

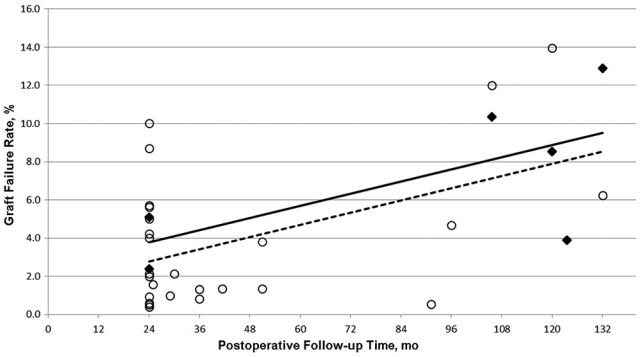

Figure 4. Scatterplot of summary graft failure rates (%) and mean postoperative follow-up time (months), comparing autograft types. Studies reporting graft failure data for patellar tendon autografts are represented by diamonds, and those reporting graft failure data for hamstring tendon autografts are represented by empty circles. Linear trendlines for both patellar tendon autografts are represented by a solid line, and hamstring tendon autografts are represented by a dashed line.

(44.5 months). This discrepancy suggests that if the mean postoperative follow-up time between the 2 autografts were equal, an increased number of HT graft failures would have accrued, and the failure rate observed for HT autografts would have likely been more similar to that of the PT autografts.

The results from the meta-regression analysis of all available data revealed that mean postoperative follow-up time positively influenced graft failure rate. Interestingly, the subgroup meta-regression analyses demonstrated that failure rate for HT autografts was significantly influenced by follow-up time, but this same effect was not significant for PT autografts. Although the slope of the regression line for HT (0.01) and PT (0.005) autografts appears to be different, their respective 95% CIs overlap. Furthermore, when plotting follow-up time by graft failure rate, the durability of both autografts appears to be equally influenced by time (Figure 4). The failure to achieve statistical significance in the PT autograft analysis was likely due to the small sample of studies providing PT graft failure data (PT = 6 data samples, HT = 26 data samples). Therefore, if more PT autograft data were available, follow-up time may have exhibited the same predictive effect on PT graft failures. However, to support the above hypotheses, more long-term follow-up anatomic ACLR studies on HT autografts and studies reporting graft failure data from PT autografts are needed.

While the summary OR (1.21) derived from the meta-analysis suggested a slightly higher odds of failure with HT autografts, this finding was not significant (P = .57). Furthermore, the 95% CI crossed 1, which verifies that little confidence can be given to differences in graft failure rate between the 2 autografts. Thus, neither autograft choice placed patients at greater odds for graft failure after anatomic ACLR. These findings further support our initial finding of no significant differences in graft failure rate between PT and HT autografts. Unlike the summary event rates and OR calculated from the 28 studies included in this review, the meta-analysis consisted of only the 4 studies[47,48,52,63] that prospectively compared postoperative outcomes between PT and HT autografts. When combining the data on graft failures of these 4 studies, the graft failure rates for PT and HT autografts are both 8.8%. These graft failure rates are in agreement with those reported in our results, because they demonstrate no significant differences. Given that these 4 studies directly compared graft failures between PT and HT autografts, they provide high-level evidence to reject differences in graft failure rate between PT and HT autografts.

Our findings refute those of a recent study from the Danish ACL registry that compared the risk of ACL revision surgery between anatomic and nonanatomic ACLR techniques.[50] They found anatomic ACLR to be associated with an increased risk of revision compared with nonanatomic techniques, but when stratifying their analyses by autograft type, this difference was only true for patients who received HT autografts (relative risk, 2.2) and not for those who received PT autografts. Therefore, it was concluded that patients who receive HT autografts are at a greater risk of failure when an anatomic ACLR technique is performed. A major limitation of their study is that they only reported data on ACL revisions and did not capture data on patients who tore their ACL graft but had not undergone a revision. This prevented them from reporting true event rates because they did not account for those patients who tore their graft and have yet to undergo a revision surgery. An advantage of this current review is that we defined graft failure as either an ACL revision or graft tear (excluding Cyclops lesions), thus allowing us to more accurately report the event rate for graft failure.

Within the past 30 years, there have been a number of systematic reviews and meta-analyses comparing postoperative outcomes between PT and HT autografts, not specifically comparing the graft placement technique (anatomic or nonanatomic) used for ACLR.[8,17,19,34-36,51,53] Even with this breadth of literature, the evidence for differences in graft failure rate remains inconclusive. Some of these studies[17,19,51] reported lower graft failure rates for PT autografts compared with HT autografts, while

the other studies have reported no significant differences between the 2 autografts with regard to graft failure rate.[34-36,53] A possible explanation as to why a higher graft failure rate was observed in some of the studies could be due to the slower bone-tunnel healing rate of HT autografts compared with PT autografts. It has been established that more time (≥1 year) is needed for HT autografts to fully mature compared with nonsynovialized grafts such as PT autografts.[28,37] Therefore, a more delayed return to dynamic activities may be warranted for patients with HT autografts.

A higher graft failure rate for anatomic ACLR compared with nonanatomic techniques has previously been reported in a systematic review by Alentorn-Geli et al.[4] Their results indicated that 5.7% of patients in the anatomic ACLR group sustained graft failures, while only 2.3% of patients in the nonanatomic ACLR group failed. Their graft failure rate for anatomic ACLR was similar to what was reported in this review (4.6%). However, anatomic ACLR has repeatedly been shown to be superior in restoring anterior-posterior and rotational stability in the knee compared with nonanatomic techniques,[4,5,16,24] thus allowing patients to return to dynamic activities sooner.[4,5] It has been demonstrated that anatomically placed grafts carry greater loads compared with nonanatomically placed grafts.[64] It is hypothesized that patients who receive anatomic ACLR are more likely to return to dynamic activities too soon, exposing their graft to greater loads and therefore putting them at a greater risk for failure before their graft has fully matured.[18,50] These patterns may help to explain why early ACL graft failure and revision rates have been reported to be higher for anatomic ACLR compared with nonanatomic techniques. However, this causal relationship cannot be determined until more studies report return to activity data after anatomic ACLR.

The true advantage of anatomic ACLR techniques may not lie in the first 2 postoperative years but in the long-term condition of the knee. While transtibial ACLR has relatively low early graft failure rates, the rate of long-term failure due to degenerative changes and osteoarthritis is tremendous. More than half of transtibial ACLR patients demonstrated radiographic evidence of grade 2 or higher joint degenerative changes at 14 years.[7,61] As such, the potential advantages of improved anterior-posterior and rotational stability associated with anatomic techniques may not be realized until longer follow-up is available.

Return to Preinjury Activity Levels

The event rate of patients who return to their preinjury activity levels after ACLR is a postoperative measure that is underreported in outcome studies but largely determines the degree of recovery in patients. The RTAL rate reported in this review appears to be different between PT and HT autografts (58.1% vs 75.6%, respectively), but due to only a single PT study reporting RTAL and the wide CIs observed among HT studies, a true statistical difference between the 2 autografts could not be concluded. The RTAL rate reported for PT autografts in this review is derived from 1 study by Sajovic et al[52] that examined 11-year follow-up outcomes. Although this study provided a high level of evidence, being a randomized clinical trial, it should still be interpreted with caution since the data were extracted from one sample. More prospective, comparative studies that report RTAL data in patients who have undergone anatomic ACLR are needed to perform meta-analyses and truly assess differences in RTAL rate between PT and HT autografts.

Our results also revealed that 71.7% of the patients for whom RTAL data were provided returned to their preinjury activity levels after anatomic ACLR. This value was in agreement with what we expected for anatomic ACLR. In a retrospective comparative study, Franceschi et al[16] observed that at a minimum postoperative follow-up of 5 years, more than 80% of the patients who underwent anatomic ACLR (with HT autografts) returned to their preinjury activity levels, whereas only 65% of patients returned to their preinjury activity levels after nonanatomic ACLR. Furthermore, studies[4,5,24] comparing these 2 ACLR techniques have demonstrated that patients who have undergone an anatomic technique return to activities of daily living sooner and have better subjective knee outcome scores than those who have undergone nonanatomic techniques. Since anatomic ACLR has been shown to restore functional knee stability more effectively than nonanatomic techniques,[4,5,24] it is logical to assume that patients' knees will feel more like "normal," making them more likely to return to the same activities they had participated in before sustaining an ACL injury.

Quality of Literature

The overall CMS score for all 28 studies included in this systematic review was 81.6 out of 100. This score was encouraging given the number of case series and retrospective studies that were included. Despite the moderately high CMS score of the studies included in this review, the strength of recommendation of this review can only be considered as evidence level 2.[13] When examining the CMS scores by autograft type, differences in methodological quality can be observed. The studies assessing both PT and HT autografts scored moderately high on the CMS (80.2/100 and 82.1/100, respectively). The most common reasons why studies lost points on the CMS were because they did not report the reliability/validity of their outcome measures, or the investigators were not independent of the surgeon.

Limitations

Several limitations involved in this review should be considered when interpreting the results. Of 28 studies included in this review, only 4 prospectively compared postoperative outcomes between autograft types used for anatomic ACLR. For the rest of the studies, we extracted cohort data on patients who underwent anatomic ACLR and whose data were specified by autograft type. The literature on postoperative outcomes after anatomic ACLR has been published only within the past decade; thus, it was foreseen that there would be a limited number of high-level

evidence studies. We did not elect to only review the 4 aforementioned studies because our aim was to provide a comprehensive review on all available evidence to answer our clinical question.

Another limitation of this review was that the data samples and mean postoperative follow-up periods were not equal between autograft types. The number of data samples was substantially higher for HT autografts (26 samples) compared with PT autografts (6 samples). Although the PT autograft studies provided nearly 400 patients, the more than 2000 patients provided by the HT autograft studies gives them an advantage related to representation of the data. Conversely, the PT autograft studies demonstrated a longer mean postoperative period of more than 7 years (almost 4 years longer than the HT studies). Although an inclusion criterion was that postoperative outcome data must be reported at least 24 months after anatomic ACLR to be included in this review, we did not put a limit on the length of follow-up. If the follow-up periods for the HT autograft studies were the same length as the PT autograft studies, we may have observed a greater number of subsequent graft failures in that population. This hypothesis is further supported by the meta-regression data demonstrating a significant relationship between follow-up time and graft failure rate among HT autograft studies.

Lastly, we were unable to determine whether there were differences in the time span from anatomic ACLR to graft failure between PT and HT autografts. These data would have provided insight into the longevity and the temporal failure trends of both autografts and whether these characteristics were different between the two. Assessing the time to failure of anatomically placed autografts was a preliminary goal of this review. However, during the data extraction process, it became evident that only a minority of the studies included in this review provided time-to-failure information on those patients who sustained graft failure after anatomic ACLR. Although we found postoperative follow-up time to have a positive association with graft failure rate, there were not enough data available for us to determine when most of these graft failures took place after surgery or whether there were temporal differences between autografts. Time to failure is a factor that warrants attention and should be assessed to gain more knowledge about the durability of surgical techniques used with ACLR.

CONCLUSION

The results from this review demonstrated a low rate of graft failure for anatomic ACLR, with no significant differences in failure rates between PT and HT autografts. Furthermore, there was no difference in the odds of graft failure between PT and HT autografts when using an anatomic ACLR technique. Graft failure rates for anatomic ACLR were influenced by postoperative follow-up time, but this effect was significant only for HT autografts. This same temporal effect was not demonstrated with PT graft failure rates, likely due to the smaller sample of studies compared with HT autografts. Just over 70% of the patients who underwent anatomic ACLR were observed to return to their preinjury levels of activity, with no differences between autografts. Due to the lack of randomized clinical trials comparing postoperative outcomes between autografts used for anatomic ACLR, we are unable to definitively conclude that one graft is superior with regard to achieving a successful recovery. Since graft integrity and returning patients to their preinjury activity levels largely define surgical success, it is strongly encouraged that further research be conducted assessing these postoperative outcomes in patients who have undergone anatomic ACLR. In addition, future investigations comparing postoperative outcomes between surgical techniques are encouraged to account for differences in postoperative follow-up time when conducting their analyses.

REFERENCES

1. Aglietti P, Giron F, Cuomo P, Losco M, Mondanelli N. Single-and double-incision double-bundle ACL reconstruction. *Clin Orthop Relat Res*. 2007;454:108-113.
2. Aglietti P, Giron F, Losco M, Cuomo P, Ciardullo A, Mondanelli N. Comparison between single-and double-bundle anterior cruciate ligament reconstruction: a prospective, randomized, single-blinded clinical trial. *Am J Sports Med*. 2010;38(1):25-34.
3. Ahldén M, Sernert N, Karlsson J, Kartus J. A prospective randomized study comparing double- and single-bundle techniques for anterior cruciate ligament reconstruction. *Am J Sports Med*. 2013;41(11): 2484-2491.
4. Alentorn-Geli E, Lajara F, Samitier G, Cugat R. The transtibial versus the anteromedial portal technique in the arthroscopic bone–patellar tendon–bone anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(8):1013-1037.
5. Alentorn-Geli E, Samitier G, Alvarez P, Steinbacher G, Cugat R. Anteromedial portal versus transtibial drilling techniques in ACL reconstruction: a blinded cross-sectional study at two- to five-year follow-up. *Int Orthop*. 2010;34(5):747-754.
6. Arna Risberg M, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? *Phys Ther Sport*. 2004;5(3):125-145.

7. Barenius B, Ponzer S, Shalabi A, Bujak R, Norlén L, Eriksson K. Increased risk of osteoarthritis after anterior cruciate ligament reconstruction a 14-year follow-up study of a randomized controlled trial. *Am J Sports Med*. 2014;42(5):1049-1057.
8. Biau DJ, Tournoux C, Katsahian S, Schranz P, Nizard R. ACL reconstruction: a meta-analysis of functional scores. *Clin Orthop Relat Res*. 2007;458:180-187.
9. Biau DJ, Tournoux C, Katsahian S, Schranz PJ, Nizard RS. Bone–patellar tendon–bone autografts versus hamstring autografts for reconstruction of anterior cruciate ligament: meta-analysis. *BMJ*. 2006;332(7548):995-1001.
10. Bizzini M, Gorelick M, Munzinger U, Drobny T. Joint laxity and isokinetic thigh muscle strength characteristics after anterior cruciate ligament reconstruction: bone patellar tendon bone versus quadrupled hamstring autografts. *Clin J Sport Med*. 2006;16(1):4-9.
11. Coleman BD, Khan KM, Maffulli N, Cook JL, Wark JD. Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies. Victorian Institute of Sport Tendon Study Group. *Scand J Med Sci Sports*. 2000;10(1):2-11.
12. Duffee A, Magnussen RA, Pedroza AD, Flanigan DC, Kaeding CC. Transtibial ACL femoral tunnel preparation increases odds of repeat ipsilateral knee surgery. *J Bone Joint Surg Am*. 2013;95(22):2035-2042.
13. Ebell MH, Siwek J, Weiss BD, et al. Strength of recommendation taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician*. 2004;69(3):548-556.
14. Felmet G. Implant-free press-fit fixation for bone–patellar tendon–bone ACL reconstruction: 10-year results. *Arch Orthop Trauma Surg*. 2010;130(8):985-992.
15. Ferretti A, Vadala A, De Carli A, Argento G, Conteduca F, Severini G. Minimizing internal rotation strength deficit after use of semitendinosus for anterior cruciate ligament reconstruction: a modified harvesting technique. *Arthroscopy*. 2008;24(7):786-795.
16. Franceschi F, Papalia R, Rizzello G, Del Buono A, Maffulli N, Denaro V. Anteromedial portal versus transtibial drilling techniques in anterior cruciate ligament reconstruction: any clinical relevance? A retrospective comparative study. *Arthroscopy*. 2013;29(8):1330-1337.
17. Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR. Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. *Am J Sports Med*. 2003;31(1):2-11.
18. Getgood A, Spalding T. The evolution of anatomic anterior cruciate ligament reconstruction. *Open Orthop J*. 2012;6:287-294.
19. Gifstad T, Sole A, Strand T, Uppheim G, Grontvedt T, Drogset JO. Long-term follow-up of patellar tendon grafts or hamstring tendon grafts in endoscopic ACL reconstructions. *Knee Surg Sports Traumatol Arthrosc*. 2012;21(3):576-583.
20. Gobbi A, Mahajan V, Karnatzikos G, Nakamura N. Single- versus double-bundle ACL reconstruction: is there any difference in stability and function at 3-year followup? *Clin Orthop Relat Res*. 2012; 470(3):824-834.
21. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-1558.
22. Howard JS, Lattermann C, Hoch JM, Mattacola CG, Medina McKeon JM. Comparing responsiveness of six common patient-reported outcomes to changes following autologous chondrocyte implantation: a systematic review and meta-analysis of prospective studies. *Cartilage*. 2013;4(2):97-110.
23. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Individualized anterior cruciate ligament surgery: a prospective study comparing anatomic single- and double-bundle reconstruction. *Am J Sports Med*. 2012;40(8):1781-1788.
24. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3- to 5-year follow-up. *Am J Sports Med*. 2012;40(3):512-520.
25. Ibrahim SA, Al-Kussary IM, Al-Misfer AR, Al-Mutairi HQ, Ghafar SA, El Noor TA. Clinical evaluation of arthroscopically assisted anterior cruciate ligament reconstruction: patellar tendon versus gracilis and semitendinosus autograft. *Arthroscopy*. 2005;21(4):412-417.
26. Ibrahim SA, Hamido F, Al Misfer AK, Mahgoob A, Ghafar SA, Alhran H. Anterior cruciate ligament reconstruction using autologous hamstring double bundle graft compared with single bundle procedures. *J Bone Joint Surg Br*. 2009;91(10):1310-1315.
27. Jagodzinski M, Geiges B, von Falck C, et al. Biodegradable screw versus a press-fit bone plug fixation for hamstring anterior cruciate ligament reconstruction: a prospective randomized study. *Am J Sports Med*. 2010;38(3):501-508.
28. Janssen RP, Scheffler SU. Intra-articular remodelling of hamstring tendon grafts after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(9):2102-2108.
29. Jarvela T, Moisala AS, Sihvonen R, Jarvela S, Kannus P, Jarvinen M. Double-bundle anterior cruciate ligament reconstruction using hamstring autografts and bioabsorbable interference screw fixation: prospective, randomized, clinical study with 2-year results. *Am J Sports Med*. 2008;36(2):290-297.
30. Kartus J, Magnusson L, Stener S, Brandsson S, Eriksson BI, Karlsson J. Complications following arthroscopic anterior cruciate ligament reconstruction: a 2–5-year follow-up of 604 patients with special emphasis on anterior knee pain. *Knee Surg Sports Traumatol Arthrosc*. 1999;7(1):2-8.
31. Kondo E, Yasuda K, Azuma H, Tanabe Y, Yagi T. Prospective clinical comparisons of anatomic double-bundle versus single-bundle anterior cruciate ligament reconstruction procedures in 328 consecutive patients. *Am J Sports Med*. 2008;36(9):1675-1687.
32. Kondo E, Yasuda K, Miyatake S, Kitamura N, Tohyama H, Yagi T. Clinical comparison of two suspensory fixation devices for anatomic double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(7):1261-1267.
33. Laxdal G, Kartus J, Eriksson BI, Faxen E, Sernert N, Karlsson J. Biodegradable and metallic interference screws in anterior cruciate ligament reconstruction surgery using hamstring tendon grafts: prospective randomized study of radiographic results and clinical outcome. *Am J Sports Med*. 2006;34(10):1574-1580.
34. Li S, Chen Y, Lin Z, Cui W, Zhao J, Su W. A systematic review of randomized controlled clinical trials comparing hamstring autografts versus bone–patellar tendon–bone autografts for the reconstruction of the anterior cruciate ligament. *Arch Orthop Trauma Surg*. 2012; 132(9):1287-1297.
35. Li S, Su W, Zhao J, et al. A meta-analysis of hamstring autografts versus bone–patellar tendon–bone autografts for reconstruction of the anterior cruciate ligament. *Knee*. 2011;18(5):287-293.
36. Magnussen RA, Carey JL, Spindler KP. Does autograft choice determine intermediate-term outcome of ACL reconstruction? *Knee Surg Sports Traumatol Arthrosc*. 2011;19(3):462-472.
37. Marumo K, Saito M, Yamagishi T, Fujii K. The ''ligamentization'' process in human anterior cruciate ligament reconstruction with autogenous patellar and hamstring tendons: a biochemical study. *Am J Sports Med*. 2005;33(8):1166-1173.
38. Matsumoto A, Yoshiya S, Muratsu H, et al. A comparison of bone–patellar tendon–bone and bone-hamstring tendon-bone autografts for anterior cruciate ligament reconstruction. *Am J Sports Med*. 2006;34(2):213-219.
39. Mithoefer K, McAdams T, Williams RJ, Kreuz PC, Mandelbaum BR. Clinical efficacy of the microfracture technique for articular cartilage repair in the knee an evidence-based systematic analysis. *Am J Sports Med*. 2009;37(10):2053-2063.
40. Nunez M, Sastre S, Nunez E, Lozano L, Nicodemo C, Segur JM. Health-related quality of life and direct costs in patients with anterior cruciate ligament injury: single-bundle versus double-bundle reconstruction in a low-demand cohort—a randomized trial with 2 years of follow-up. *Arthroscopy*. 2012;28(7):929-935.
41. OCEBM Levels of Evidence Working Group. Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence. Oxford Centre for Evidence-Based Medicine; 2011. http://www.cebm.net/index.aspx?o=5653. Accessed May 2015.

42. O'Donnell JB, Scerpella TA. Endoscopic anterior cruciate ligament reconstruction: modified technique and radiographic review. *Arthroscopy*. 1995;11(5):577-584.
43. O'Neill DB. Arthroscopically assisted reconstruction of the anterior cruciate ligament: a prospective randomized analysis of three techniques. *J Bone Joint Surg Am*. 1996;78(6):803-813.
44. Otsuka H, Ishibashi Y, Tsuda E, Sasaki K, Toh S. Comparison of three techniques of anterior cruciate ligament reconstruction with bone–patellar tendon–bone graft: differences in anterior tibial translation and tunnel enlargement with each technique. *Am J Sports Med*. 2003;31(2):282-288.
45. Papalia R, Del Buono A, Osti L, Denaro V, Maffulli N. Meniscectomy as a risk factor for knee osteoarthritis: a systematic review. *Br Med Bull*. 2011;99(1):89-106.
46. Piasecki DP, Bach BR Jr, Espinoza Orias AA, Verma NN. Anterior cruciate ligament reconstruction: can anatomic femoral placement be achieved with a transtibial technique? *Am J Sports Med*. 2011;39(6):1306-1315.
47. Pinczewski LA, Deehan DJ, Salmon LJ, Russell VJ, Clingeleffer A. A five-year comparison of patellar tendon versus four-strand hamstring tendon autograft for arthroscopic reconstruction of the anterior cruciate ligament. *Am J Sports Med*. 2002;30(4):523-536.
48. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. *Am J Sports Med*. 2007;35(4):564-574.
49. Plaweski S, Rossi J, Merloz P. Anterior cruciate ligament reconstruction: assessment of the hamstring autograft femoral fixation using the EndoButton CL. *Orthop Traumatol Surg Res*. 2009;95(8):606-613.
50. Rahr-Wagner L, Thillemann TM, Pedersen AB, Lind MC. Increased risk of revision after anteromedial compared with transtibial drilling of the femoral tunnel during primary anterior cruciate ligament reconstruction: results from the Danish Knee Ligament Reconstruction Register. *Arthroscopy*. 2013;29(1):98-105.
51. Reinhardt KR, Hetsroni I, Marx RG. Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. *Orthop Clin North Am*. 2010;41(2):249-262.
52. Sajovic M, Strahovnik A, Dernovsek MZ, Skaza K. Quality of life and clinical outcome comparison of semitendinosus and gracilis tendon versus patellar tendon autografts for anterior cruciate ligament reconstruction: an 11-year follow-up of a randomized controlled trial. *Am J Sports Med*. 2011;39(10):2161-2169.
53. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring does it really matter? A systematic review. *Am J Sports Med*. 2004;32(8):1986-1995.
54. Stener S, Ejerhed L, Sernert N, Laxdal G, Rostgard-Christensen L, Kartus J. A long-term, prospective, randomized study comparing biodegradable and metal interference screws in anterior cruciate ligament reconstruction surgery: radiographic results and clinical outcome. *Am J Sports Med*. 2010;38(8):1598-1605.
55. Sun K, Zhang J, Wang Y, et al. Arthroscopic anterior cruciate ligament reconstruction with at least 2.5 years' follow-up comparing hamstring tendon autograft and irradiated allograft. *Arthroscopy*. 2011;27(9):1195-1202.
56. 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.
57. Suomalainen P, Moisala AS, Paakkala A, Kannus P, Jarvela T. Comparison of tunnel placements and clinical results of single-bundle anterior cruciate ligament reconstruction before and after starting the use of double-bundle technique. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(3):646-653.
58. Tallon C, Coleman BD, Khan KM, Maffulli N. Outcome of surgery for chronic Achilles tendinopathy a critical review. *Am J Sports Med*. 2001;29(3):315-320.
59. Tohyama H, Kondo E, Hayashi R, Kitamura N, Yasuda K. Gender-based differences in outcome after anatomic double-bundle anterior cruciate ligament reconstruction with hamstring tendon autografts. *Am J Sports Med*. 2011;39(9):1849-1857.
60. van Eck CF, Lesniak BP, Schreiber VM, Fu FH. Anatomic single- and double-bundle anterior cruciate ligament reconstruction flowchart. *Arthroscopy*. 2010;26(2):258-268.
61. Von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis*. 2004;63(3):269-273.
62. Wagner M, Kaab MJ, Schallock J, Haas NP, Weiler A. Hamstring tendon versus patellar tendon anterior cruciate ligament reconstruction using biodegradable interference fit fixation: a prospective matched-group analysis. *Am J Sports Med*. 2005;33(9):1327-1336.
63. Wipfler B, Donner S, Zechmann CM, Springer J, Siebold R, Paessler HH. Anterior cruciate ligament reconstruction using patellar tendon versus hamstring tendon: a prospective comparative study with 9-year follow-up. *Arthroscopy*. 2011;27(5):653-665.
64. Xu Y, Liu J, Kramer S, et al. Comparison of in situ forces and knee kinematics in anteromedial and high anteromedial bundle augmentation for partially ruptured anterior cruciate ligament. *Am J Sports Med*. 2011;39(2):272-278.
65. Yasuda K, Kondo E, Ichiyama H, Tanabe Y, Tohyama H. Clinical evaluation of anatomic double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: comparisons among 3 different procedures. *Arthroscopy*. 2006;22(3):240-251.
66. Zaffagnini S, Bruni D, Russo A, et al. ST/G ACL reconstruction: double strand plus extra-articular sling vs double bundle, randomized study at 3-year follow-up. *Scand J Med Sci Sports*. 2008;18(5):573-581.