Systematic Review

# Patients Have Similar Clinical Outcomes and Failure Rates After Anterior Cruciate Ligament Reconstruction With Tibialis Anterior Tendon, Bone—Patellar Tendon—Bone, Hamstring Tendon, or Achilles Tendon Allografts: A Systematic Review

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**Purpose:** To compare postoperative outcomes and functionality in patients who undergo primary allograft anterior cruciate ligament reconstruction (ACLR) with tibialis anterior (TA) tendon, bone—patellar tendon—bone (BPTB), hamstring tendon (HT), and Achilles tendon allografts. **Methods:** In April 2024, a comprehensive search of the PubMed, Embase, and Cochrane Library databases was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines. Studies were included if they evaluated primary ACLR using allograft, were prospective randomized controlled trials or retrospective studies, compared outcomes in patients undergoing primary ACLR with different allograft types, and were published between 2000 and 2024. Data collection included patient demographic characteristics, graft type, activity level, drilling technique, concomitant and augmentation procedures, patient-reported outcome measures, complications, and graft rerupture rates. Pooling of data was avoided, and qualitative data comparison was conducted. **Results:** The initial search identified 957 studies, 7 of which were included in this systematic review. Of these, 5 were randomized controlled trials and 2 were retrospective studies. A total of 735 patients were included, with 167 HT patients, 252 BPTB patients, 162 TA patients, and 153 Achilles patients. The mean ages within the cohorts ranged from 23.9 to 37.2 years. The mean follow-up times across studies ranged from 25.6 to 90.0 months. Demographic characteristics were similar among the graft cohorts, and each study had a low risk of bias. Failure rates ranged from 2% to 65% across studies. Similar International Knee Documentation Committee, Lysholm, and Tegner scores were reported among the graft types. Additionally, similar functional outcomes as measured by side-by-side differences in arthrometer readings and similar complication rates after primary ACLR with HT, BPTB, TA, and Achilles allografts were found. **Conclusions:** Primary ACLR with allografts in patients older than 23 years is safe and effective with few differences in patient-reported outcomes, postoperative function, and graft failure rates among graft options. **Level of Evidence:** Level IV, systematic review of Level I to IV studies.

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The anterior cruciate ligament (ACL) is critical to appropriate stability and function of the knee. ACL reconstruction (ACLR) aims to restore rotational and sagittal stability after injury.[1-3] ACLR can be performed using either autograft or allograft tissue, with allografts being used in an estimated 22% to 42% of cases.[4] There has been controversy over the use of allografts in ACLR, particularly in younger patients, with prior reports noting higher rerupture rates.[5,6] Interest remains in defining populations of patients who may be appropriate candidates for allograft use and determining whether rehabilitation protocol adjustments

with allograft use may allow for comparable outcomes to autografts, even in younger patients. Prior work has shown that allograft ACLR is best suited for older, less active patients.[7] However, allograft ACLR has been shown to yield excellent outcomes in younger patient populations who comply with more slowly paced rehabilitation and return-to-sport protocols.[7,8] The benefit of allografts is the absence of ACL donor-site morbidity associated with autograft harvesting.[9,10] Common allografts used for ACLR include tibialis anterior (TA) tendon, Achilles tendon, hamstring tendon (HT), and bone–patellar tendon–bone (BPTB).[11,12]

The optimal allograft to allow patients to return to desired activities while minimizing rerupture rates remains a topic of debate. Previous studies have shown that TA allografts provide satisfactory outcomes in patients with minimum 2-year follow-up, with a 5.2% rerupture rate[13] and 94% of patients receiving normal or nearly normal grades per the International Knee Documentation Committee (IKDC) score.[14] Furthermore, TA is often used for recreational athletes aged 40 years and older and has been associated with persistent postoperative knee laxity at times.[13,14] Achilles allografts have been previously shown to provide relative long-term stability in young athletes, with rerupture rates of 5.6% to 12.0% at mean follow-up times of 40 to 72 months.[15-17] Similarly, hamstring allografts provide satisfactory knee stability, with 88.4% of patients having normal or nearly normal IKDC scores postoperatively after ACLR relative to preoperative function.[18] BPTB allografts have also been shown to be an effective option, with low revision rates (3.7%-6%) in patients who are not elite athletes, to avoid donor-site morbidity.[19,20]

The purpose of this systematic review was to compare postoperative outcomes and functionality in patients who undergo primary allograft ACLR with TA tendon, BPTB, HT, and Achilles tendon allografts. We hypothesized that there would be similar outcomes across allograft types, with similar graft rerupture rates.

## Methods

### Literature Search

A comprehensive search of the PubMed, Embase, and Cochrane Library databases was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines in April 2024. The following search strategy was used: "('anterior cruciate ligament reconstruction' OR 'ACL reconstruction' OR 'ACLR') AND ('allograft') NOT ('autograft') NOT ('revision' OR 'retear' OR 're-tear' OR 'reoperation' OR 're-op*') NOT ('cadaver') NOT ('biomech*') NOT ('systematic review') NOT ('metaanalysis' OR 'meta-analysis')." The search was conducted by one of the authors (U.D.).

Studies were included if they evaluated male and female patients of any age group who underwent primary ACLR, were prospective randomized controlled trials (RCTs) or retrospective studies, compared outcomes in patients undergoing primary ACLR with 1 type of allograft with those in patients undergoing primary ACLR with a different type of allograft, and were published between 2000 and 2024. We excluded translational studies or cadaveric studies, studies of revision ACLR patients, studies that did not directly compare patients receiving different allografts, studies with less than 18-month follow-up, and study designs consisting of systematic reviews, narrative reviews, conference abstracts, technical notes, letters to editors, or meta-analyses. Two authors (U.D. and J.B.V-E.) independently screened the titles, abstracts, and full article texts using the online software program Covidence (Veritas Health Innovation, Melbourne, Australia). Any disagreements were resolved by discussion leading to consensus between the 2 screening authors (U.D. and J.B.V-E.).

### Data Extraction and Quality Assessment

Data items extracted from each study included the total number of patients who received each allograft type for ACLR; patient sex; patient activity level; drilling technique; concomitant and augmentation procedures; preoperative and postoperative patient-reported outcome measures (PROMs) including the IKDC score, Tegner score, and Lysholm score; complications, and graft rerupture rates. Disaggregation of study data by sex was not performed because no included studies divided patients based on gender or sex, and the effects of patient gender or sex on outcomes was not evaluated in our systematic review. Assessment of study quality for RCTs was performed using the Cochrane Collaboration risk-of-bias tool,[21] and nonrandomized retrospective study quality assessment was performed with the Methodological Index for Non-randomized Studies criteria.[22]

### Statistical Analysis

Pooling of data was avoided because of a high risk of bias. As a result, a qualitative data comparison was conducted. Eligible studies were entered into Open Meta Analyst software (Brown University, Providence, RI) to create single-leg forest plots illustrating PROMs and functional scores by entering means and standard deviations for each study. This software was also used to calculate $I^2$ values, which were used to objectively evaluate heterogeneity within the studies included in this systematic review. Preoperative measures, postoperative measures, and changes in mean scores were computed when applicable.

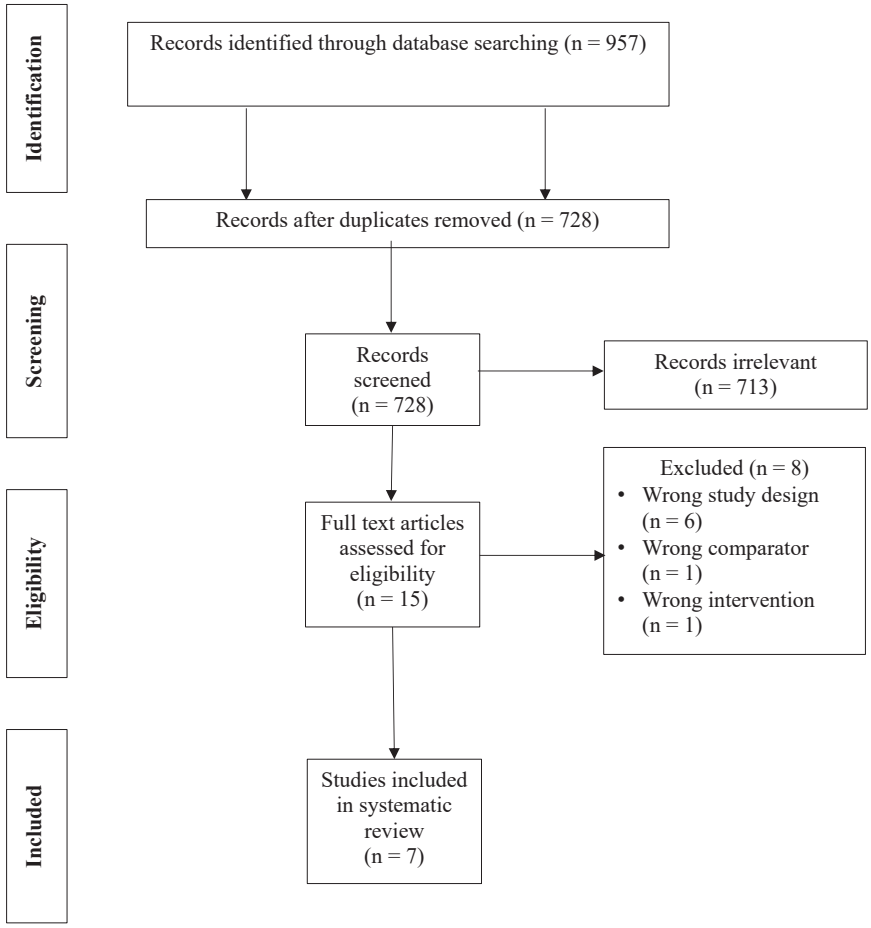


**Fig 1.** Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) study selection flow diagram. The numbers of screened, excluded, and included studies are shown.

## Results

### Search Results

A total of 957 studies were identified in the initial search, 229 of which were duplicates and were subsequently excluded. The remaining 728 studies underwent title and abstract screening; of these, 713 were found to be irrelevant to the study aims and therefore excluded. The remaining 15 studies were assessed for eligibility with full-text review. After the exclusion of 8 studies owing to an incorrect study design, comparator, or intervention, 7 studies were ultimately included for data extraction (Fig 1). Table 1 summarizes the study characteristics. The included studies had both RCT and retrospective study designs, and all evaluated PROMs.

### Study Characteristics

#### Demographic Characteristics

Seven studies with a total of 735 patients met the inclusion criteria and were included in this systematic review.[23-29] For analysis, patients were grouped into 4 different cohorts based on the type of allograft they received: HT, BPTB, TA, and Achilles. Three studies evaluated HT allografts,[23,26,28] 5 studies evaluated BPTB allografts,[23,24,26,27,29] 4 studies evaluated TA allografts,[24,25,27,28] and 2 studies evaluated Achilles allografts.[25,29] Five of the included studies were RCTs,[23,24,26,28,29] and 2 were retrospective studies.[25,27]

In the 3 studies that evaluated HT allografts, there were a total of 167 patients, with 96 male patients (57.5%).[23,26,28] Across these studies, the mean age ranged from 27 to 36 years and the minimum follow-up time ranged from 24 to 52 months.[23,26,28]

In the 5 studies that evaluated BPTB allografts, there were a total of 252 patients, with 144 male patients (57.1%).[24-28] Across these studies, the mean age ranged from 23.9 to 31.0 years and the minimum follow-up time ranged from 24 to 52 months.[24-28]

In the 4 studies that evaluated TA allografts, there were a total of 162 patients, with 105 male patients (64.8%).[24,25,27,28] Across these studies, the mean age ranged from 24.2 to 37.2 years and the minimum follow-up time ranged from 18 to 66 months.[24,25,27,28]

The 2 studies that evaluated Achilles allografts included 154 total patients, with 102 male patients (66.2%).[25,29] The mean age in the Achilles cohort

**Table 1.** Summary of Demographic Characteristics of Included Studies and Patient Cohorts

| Cohort | N | Mean Age (SD), yr | Male Sex, n (%) | Mean Follow-Up (SD), mo | Population |
|---|---|---|---|---|---|
| HT | | | | | |
| Dai et al.,[23] 2016 | 69 | 30.0 (6.0) | 36 (52.2) | 52.0 (9.5) | Not specified |
| Rose et al.,[28] 2016 | 47 | 34.6 (2.9) | 33 (70.0) | 29.5 (8.3) | 40% athletes (baseline Tegner score > 7) |
| Niu et al.,[26] 2016 | 51 | 27.0 (4.0) | 27 (52.9) | 40.0 (3.0) | Not specified |
| Total | 167 | | | | |
| BPTB | | | | | |
| Dai et al. | 60 | 29.0 (5.0) | 35 (58.3) | 52.0 (9.5) | Not specified |
| O'Brien et al.,[27] 2014 | 20 | 23.9 (4.5) | 17 (85.0) | 29.9 (16.6) | Not specified |
| Niu et al. | 50 | 26.0 (5.0) | 25 (50.0) | 40.0 (3.0) | Not specified |
| Wang et al.,[29] 2011 | 79 | 31.0 (6.4) | 47 (64.4) | 36.7 (7.0) | Not specified |
| Kang et al.,[24] 2015 | 43 | 30.0 (5) | 20 (46.5) | 31.0 (5.0) | Not specified |
| Total | 252 | | | | |
| TA | | | | | |
| Rose et al. | 51 | 37.2 (3.3) | 29 (57.0) | 30.5 (7.3) | 41% athletes (baseline Tegner score > 7) |
| O'Brien et al. | 20 | 24.2 (4.3) | 17 (85.0) | 25.6 (13.1) | Not specified |
| Kim et al.,[25] 2014 | 50 | 32.4 (7.0) | 38 (76.0) | 90.0 (16.2) | Not specified |
| Kang et al. | 41 | 28.5 (5.0) | 21 (51.2) | 33.0 (6.0) | Not specified |
| Total | 162 | | | | |
| Achilles | | | | | |
| Kim et al. | 81 | 31.7 (7.3) | 60 (74.1) | 90.0 (16.2) | Not specified |
| Wang et al. | 73 | 29.1 (5.7) | 42 (57.5) | 37.3 (7.5) | Not specified |
| Total | 153 | | | | |
| Grand total | 735 | | | | |

BPTB, bone–patellar tendon–bone; HT, hamstring tendon; SD, standard deviation; TA, tibialis anterior.

ranged from 29.1 to 31.7 years, and the minimum follow-up time ranged from 24 to 66 months.[25,29] Table 1 summarizes demographic characteristics of each of the included studies in this systematic review. Table 2 summarizes study quality based on the Methodological Index for Non-randomized Studies criteria for nonrandomized studies and the Cochrane Collaboration risk-of-bias tool for randomized studies. All included studies had a sufficiently low risk of bias.

## Surgical Techniques

Four studies used an anteromedial portal for guide placement for the tibial tunnel and a separate anteromedial or posterior portal for drilling of the femoral tunnel.[23,24,26,29] Two studies used a transtibial approach for drilling of both the tibial and femoral tunnels.[25,28] The study by O'Brien et al.[27] used a transtibial approach for tunnel drilling in the entire BPTB cohort but used a separate anteromedial portal for femoral tunnel drilling in 45% of the TA cohort. Four studies used an EndoButton (Smith & Nephew, Andover, MA) for femoral graft fixation and bioabsorbable interference screws for tibial graft fixation.[24,26-28] No studies included any augmentation procedures such as lateral extra-articular tenodesis. Only Rose et al.[28] reported how they sterilized allografts, using low-level gamma irradiation and Allowash detergent (LifeNet Health, Virginia Beach, VA). Within the HT cohort, Dai et al.[23] used 6-strand HT whereas Niu et al.[26] and Rose et al. used quadrupled tendon. Table 3 summarizes tunnel drilling and graft sterilization and fixation techniques used by each of the studies included in this systematic review.

## Patient-Reported Outcome Measures

*IKDC Score.* IKDC scores were reported by all 3 studies that evaluated HT allografts.[23,26,28] Postoperative IKDC

**Table 2.** Summary of Study Quality and Risk-of-Bias Assessment

| Study | Study Design (LOE) | Quality Assessment Score | Sufficient Study Quality |
|---|---|---|---|
| Dai et al.,[23] 2016 | RCT (I) | Low risk per Cochrane risk-of-bias tool | Yes |
| Rose et al.,[28] 2016 | RCT (I) | Low risk per Cochrane risk-of-bias tool | Yes |
| Niu et al.,[26] 2016 | RCT (I) | Low risk per Cochrane risk-of-bias tool | Yes |
| O'Brien et al.,[27] 2014 | Retrospective study (IV) | MINORS (non-comparative) score: 10 | Yes |
| Kim et al.,[25] 2014 | Retrospective study (IV) | MINORS (non-comparative) score: 10 | Yes |
| Kang et al.,[24] 2015 | RCT (I) | Low risk per Cochrane risk-of-bias tool | Yes |
| Wang et al.,[29] 2011 | RCT (I) | Low risk per Cochrane risk-of-bias tool | Yes |

NOTE. Each included study had a sufficiently low risk of bias.
LOE, level of evidence; MINORS, Methodological Index for Non-randomized Studies; RCT, randomized controlled trial.

**Table 3.** Summary of Surgical Techniques for Each Included Study

| Study | Tunnel Drilling Technique | Graft Sterilization | Graft Fixation Technique | Concomitant Procedures |
|---|---|---|---|---|
| Dai et al.,[23] 2016 | Tibial: medial portal<br>Femoral: anteromedial portal | Not reported | Femur: EndoButton (HT cohort), 1 bioabsorbable interference screw (BPTB cohort)<br>Tibia: 2 bioabsorbable interference screws | None |
| Rose et al.,[28] 2016 | Transtibial femoral single tunnel | Chemical, radiation | Femur: EndoButton<br>Tibia: 2 bioabsorbable interference screws | None |
| Niu et al.,[26] 2016 | Tibial: anteromedial portal<br>Femoral: anteromedial portal | Not reported | Femur: EndoButton<br>Tibia: 2 bioabsorbable interference screws | Meniscectomy (49.1% of HT cohort and 57.7% of BPTB cohort) |
| O'Brien et al.,[27] 2014 | Transtibial femoral single tunnel (100% of BPTB cohort and 55% of TA cohort)<br>Anteromedial portal (45% of TA cohort) | Not reported | Femur: EndoButton<br>Tibia: 1 bioabsorbable interference screw and sheath | Meniscectomy (55% of BPTB cohort and 35% of TA cohort)<br>Meniscal repair (15% of BPTB cohort and 30% of TA cohort)<br>PLC reconstruction (5% of TA cohort)<br>Removal of loose body (5% of BPTB cohort) |
| Wang et al.,[29] 2011 | Tibial: anteromedial portal<br>Femoral: anteromedial portal | Not reported | Femur: biodegradable screw<br>Tibia: cortical screw with spiked washer | Meniscectomy (number not specified) |
| Kang et al.,[24] 2015 | Tibial: anteromedial tunnel<br>Femoral: anteromedial portal | Not reported | Femur: EndoButton<br>Tibia: bioabsorbable interference screw | Meniscectomy (51% of BPTB cohort and 42% of TA cohort)<br>Meniscal repair (2% of BPTB cohort and 2% of TA cohort)<br>Chondral lesions (7% of BPTB cohort and 5% of TA cohort) |
| Kim et al.,[25] 2014 | Transtibial femoral single tunnel | Not reported | Femur: RigidFix Cross Pins (DePuy Mitek, Raynham, MA)<br>Tibia: cancellous screw with ligament washer and bioabsorbable interference screw | Not specified |

BPTB, bone–patellar tendon–bone; HT, hamstring tendon; PLC, posterolateral corner; TA, tibialis anterior.

scores were reported for all 3 HT allograft cohorts, with means ranging from 74.2 to 89.4.[23,26,28] The changes in mean IKDC scores for the HT cohorts in the studies of Dai et al.[23] and Rose et al.[28] were 25.7 and 28.3, respectively. Postoperative IKDC scores were reported by all 5 studies that evaluated BPTB allografts.[24-28] At minimum 18-month follow-up, mean IKDC scores for BPTB patients ranged from 88.5 to 92.6.[24-28] The changes in mean IKDC scores for the BPTB cohorts in the studies of Dai et al., Wang et al.,[29] and Kang et al.[24] were 22.4, 40.7, and 44.2, respectively. Three studies with TA cohorts reported mean postoperative IKDC scores, with minimum 18-month follow-up scores ranging from 74.2 to 91.1.[24,27,28] The changes in mean IKDC scores for the TA cohorts in the studies of Rose et al. and Kang et al. were 31.2 and 47.5, respectively. Only 1 of 2 studies including Achilles allograft patients[25,29] reported mean IKDC scores at minimum 2-year follow-up, with a mean of 90.6.[29] Table 4 summarizes IKDC scores for each of the cohorts included in this study. Figure 2 displays a forest plot that serves as a visual aid illustrating IKDC scores across included studies, with an $I^2$ value of 97.56%.

*Lysholm Score.* All 3 studies that evaluated HT allografts reported Lysholm scores.[23,26,28] At the 2-year follow-up mark, mean Lysholm scores were reported by all 3 studies and ranged from 75.9 to 92.8.[23,26,28] The changes in mean Lysholm scores for the HT cohorts in the studies of Dai et al.[23] and Rose et al.[28] were 29.9 and 22.9, respectively. All 5 studies that

**Table 4.** Summary of Preoperative and Postoperative IKDC Scores

| Cohort | Mean Preoperative IKDC Score (SD) | Mean Postoperative IKDC Score (SD) | Change in Mean IKDC Score |
|---|---|---|---|
| HT | | | |
| Dai et al.,[23] 2016 | 63.7 (10.1) | 89.4 (5.0) | 25.7 |
| Rose et al.,[28] 2016 | 45.9 (5.4) | 74.2 (8.9) | 28.3 |
| Niu et al.,[26] 2016 | NA | 87.0 (5.0) | NA |
| BPTB | | | |
| Dai et al. | 66.1 (9.4) | 88.5 (4.9) | 22.4 |
| O'Brien et al.,[27] 2014 | NA | 92.6 (7.8) | NA |
| Niu et al. | NA | 89.9 (5.2) | NA |
| Wang et al.,[29] 2011 | 48.7 (7.7) | 89.4 (7.9) | 40.7 |
| Kang et al.,[24] 2015 | 45.7 (9.6) | 89.9 (4.7) | 44.2 |
| TA | | | |
| Rose et al. | 43.0 (4.0) | 74.2 (5.8) | 31.2 |
| O'Brien et al. | NA | 90.3 (8.7) | NA |
| Kim et al.,[25] 2014 | 61.5 (7.5) | NA | NA |
| Kang et al. | 43.6 (10.8) | 91.1 (5.6) | 47.5 |
| Achilles tendon | | | |
| Kim et al. | 60.5 (5.9) | NA | NA |
| Wang et al. | 50.2 (7.4) | 90.6 (7.8) | 40.4 |

BPTB, bone–patellar tendon–bone; HT, hamstring tendon; IKDC, International Knee Documentation Committee; NA, not applicable; SD, standard deviation; TA, tibialis anterior.

evaluated BPTB allografts also reported Lysholm scores. At minimum 18-month follow-up, mean postoperative Lysholm scores were reported by all 5 BPTB studies and ranged from 90.1 to 92.9.[24-28] The changes in mean Lysholm scores in the studies of Dai et al., Wang et al.,[29] and Kang et al.[24] were 30.0, 30.7, and 44.2, respectively. Of the 4 studies that evaluated TA allografts, 3 reported Lysholm scores.[24,27,28] At minimum 18-month follow-up, mean Lysholm scores were reported by these 3 studies and ranged from 83.3 to 94.0.[24,27,28] The changes in mean Lysholm scores were able to be calculated for the studies by Rose et al. and Kang et al., with values of 27.2 and 42.8, respectively. Only Wang et al. reported postoperative Lysholm scores, with a mean of 92.3. The difference in preoperative and postoperative

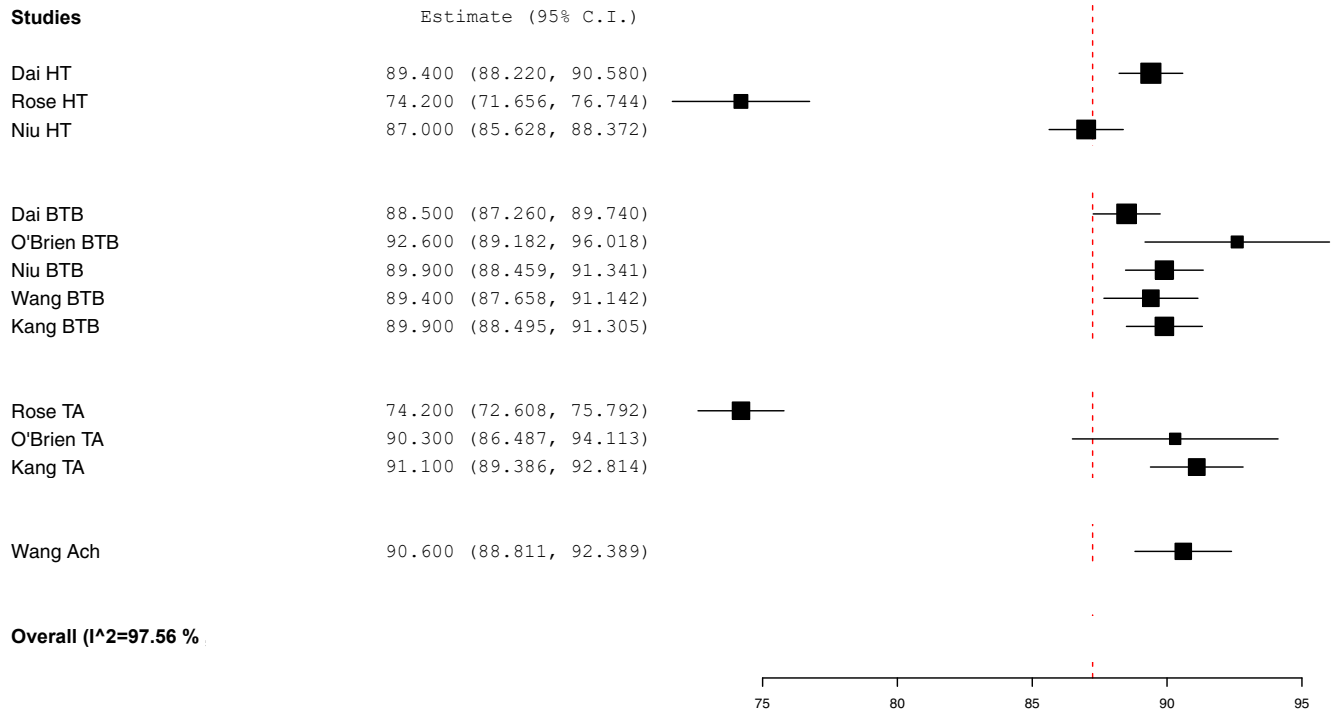


**Fig 2.** Forest plot showing mean International Knee Documentation Committee scores across included studies. Black boxes represent the mean value of each study with lines extending to the 95% confidence intervals. (Ach, Achilles tendon; BTB, bone–patellar tendon–bone; CI, confidence interval; HT, hamstring tendon; TA, tibialis anterior.)

**Table 5.** Summary of Preoperative and Postoperative Lysholm Scores

| Cohort | Mean Preoperative Lysholm Score (SD) | Mean Postoperative Lysholm Score (SD) | Change in Mean Lysholm Score |
|---|---|---|---|
| HT | | | |
| Dai et al.,[23] 2016 | 62.9 (7.3) | 92.8 (4.5) | 29.9 |
| Rose et al.,[28] 2016 | 63.0 (6.5) | 75.9 (8.3) | 22.9 |
| Niu et al.,[26] 2016 | NA | 87.3 (4.6) | NA |
| BPTB | | | |
| Dai et al. | 61.7 (6.8) | 91.7 (3.9) | 30.0 |
| O'Brien et al.,[27] 2014 | NA | 92.9 (6.0) | NA |
| Niu et al. | NA | 90.1 (5.1) | NA |
| Wang et al.,[29] 2011 | 59.8 (9.1) | 90.5 (5.5) | 30.7 |
| Kang et al.,[24] 2015 | 49.0 (10.1) | 93.2 (5.0) | 44.2 |
| TA | | | |
| Rose et al. | 56.1 (5.3) | 83.3 (7.7) | 27.2 |
| O'Brien et al. | NA | 93.0 (8.0) | NA |
| Kim et al.,[25] 2014 | 62.4 (6.4) | NA | NA |
| Kang et al. | 51.2 (13.2) | 94.0 (4.8) | 42.8 |
| Achilles tendon | | | |
| Kim et al. | 63.2 (7.2) | NA | NA |
| Wang et al. | 58.0 (10.5) | 92.3 (6.1) | 34.3 |

BPTB, bone–patellar tendon–bone; HT, hamstring tendon; NA, not applicable; SD, standard deviation; TA, tibialis anterior.

mean Lysholm scores in their study was 34.3.[29] Table 5 summarizes preoperative and postoperative Lysholm scores for each of the cohorts in this study. Figure 3 displays a forest plot that serves as a visual aid illustrating Lysholm scores across included studies, with an $I^2$ value of 96.04%.

*Tegner Score.* Of the 3 studies evaluating HT allografts, only the study of Rose et al.[28] reported Tegner scores, with a baseline preoperative mean score of 2.6 and a 2-year follow-up mean score of 5.4. The mean change in the Tegner score found by Rose et al. was 2.8. Wang et al.[29] and Kang et al.[24] reported Tegner scores for the BPTB cohort. Both studies reported postoperative Tegner scores ranging from 7.0 to 7.2 at minimum 2-year follow-up.[24,29] The mean changes in Tegner scores found by Wang et al. and Kang et al. were 3.2 and 3.0, respectively.

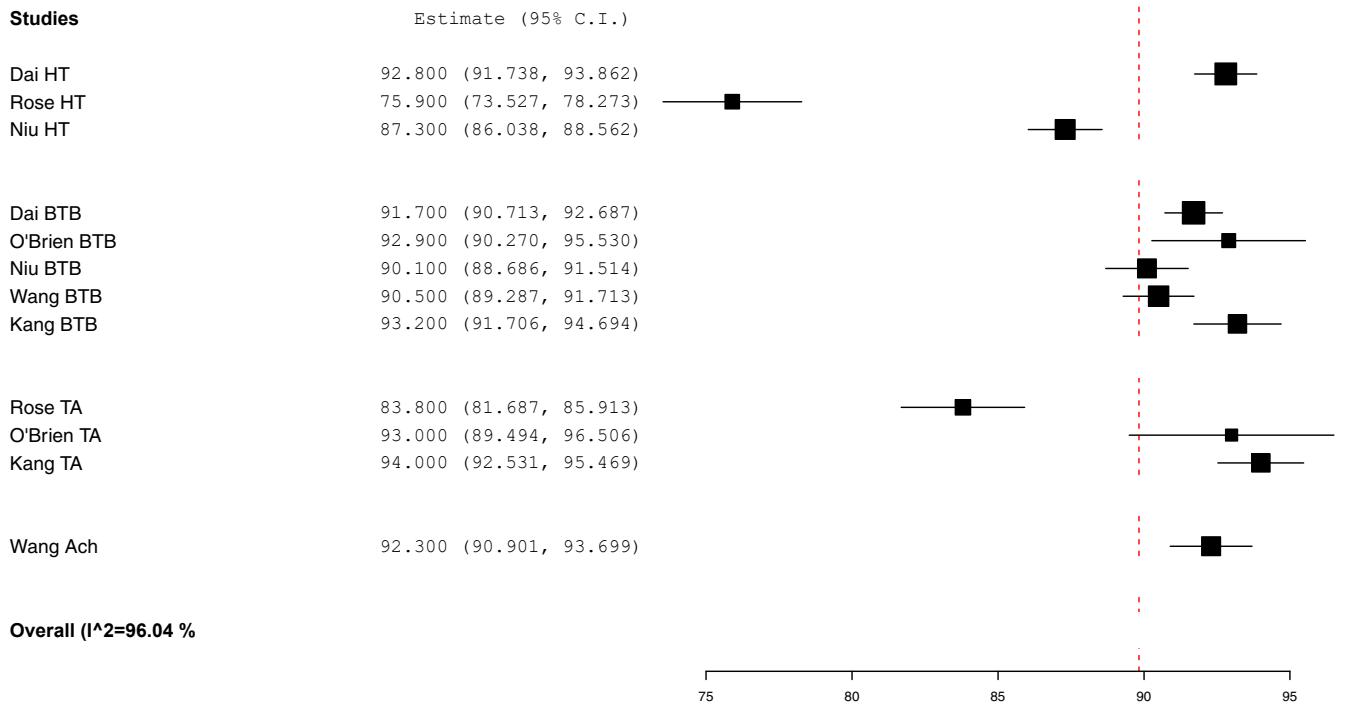


**Fig 3.** Forest plot showing mean Lysholm scores across included studies. Black boxes represent the mean value of each study with lines extending to the 95% confidence intervals. (Ach, Achilles tendon; BTB, bone–patellar tendon–bone; CI, confidence interval; HT, hamstring tendon; TA, tibialis anterior.)

Two of the TA allograft studies reported Tegner scores, with postoperative means ranging from 5.3 to 7.0.[24,28] The mean changes in Tegner scores found by Rose et al. and Kang et al. were 2.7 and 3.0, respectively. For the Achilles cohort, only Wang et al. reported postoperative Tegner scores, with a mean postoperative Tegner score of 7.0 and ultimate difference in mean Tegner score of 3.1.

### Functional Outcomes

Postoperative arthrometer measurement was performed in 2 studies evaluating HT patients, with mean side-to-side differences in anterior translation ranging from 0.88 to 1.1 mm.[23,28] Three studies evaluated postoperative KT-1000 arthrometer (MEDmetric, San Diego, CA) measurements in BPTB patients, with mean side-to-side difference in anterior translation ranging from 1.30 to 2.43 mm.[23,24] The change in mean arthrometer side-to-side difference preoperatively and postoperatively could only be calculated for the study of Wang et al.,[29] which showed a mean change of −4.52 mm. Three studies with TA patients evaluated postoperative side-to-side differences via arthrometer measurements, with mean side-to-side differences in anterior translation ranging from 0.40 to 2.1 mm.[24,25,28] The change in mean arthrometer side-to-side difference preoperatively and postoperatively could only be calculated for the study of Kim et al.,[25] which showed a mean change of −1.70 mm. Postoperative side-to-side differences in anterior translation measured for the Achilles allograft studies ranged from 1.70 to 2.40 mm.[24,25,28] The change in mean arthrometer side-to-side difference preoperatively and postoperatively was calculated to be −1.30 mm for the study of Kim et al. and −5.33 mm for the study of Wang et al.

### Complications and Reoperations

Three studies reported complication rates for HT allograft patients.[23,26,28] The ACL rerupture rate for HT allograft patients in the study by Dai et al.[23] was 5.8% (4 of 69 patients). Similarly, the rerupture rate was found to be 4.3% (2 of 47 patients) in the study by Rose et al.[28] A higher rerupture rate of 7.8% (4 of 51 patients) was found by Niu et al.[26]; however, this study also found that 17.6% of patients (9 of 51) experienced HT graft failure, for a total operative failure rate of 25.5%. Complication rates for BPTB allograft patients were reported by 5 studies.[23,24,26,27,29] The rerupture rate for BPTB patients found by Dai et al. was 10% (6 of 60 patients). Niu et al. found the retear rate for BPTB allograft patients to be 2% (1 of 50 patients) and found that 4% of patients (2 of 50) experienced graft failure. Wang et al.[29] reported a graft failure rate of 11.4% (9 of 79 patients). A much higher complication rate for BPTB patients was found by O'Brien et al.,[27] who reported that 13 of 20 patients (65%) experienced rerupture. Kang et al.[24] reported that no BPTB or TA patients had any complications. Two additional studies reported complication rates for the TA allograft group.[27,28] The rerupture rate found by Rose et al. was 2.0% (1 of 51 patients). A higher rerupture rate of 10% (2 of 20 patients) was found by O'Brien et al. Only Wang et al. reported a rerupture/graft failure rate of 2.7% (2 of 73 patients) within their Achilles allograft cohort. There was no incidence of other common surgical complications including deep vein thrombosis, superficial or deep wound infection, dehiscence, or need for additional procedures such as manipulation under anesthesia or lysis of adhesions.

## Discussion

The main findings of this study show that there are similar patient-reported outcomes (PROs), functional outcomes, complications, and reoperation rates after primary ACLR with HT, BPTB, TA, and Achilles allografts. The type of allograft chosen does not affect the outcomes of primary ACLR at short-term follow-up.

The use of allografts as opposed to autografts for primary ACLR has increased owing to the elimination of donor-site morbidity that is faced by autograft patients.[30] When choosing an allograft for patients undergoing primary ACLR, orthopaedic surgeons need to consider the graft's tensile strength, healing ability, and storage and infection risks.[30] Previous studies have shown that when patients adhere to a more slowly paced rehabilitation protocol than would be commonly prescribed after autograft ACLR, those who receive an allograft for ACLR have comparable postoperative outcomes.[7,31] Our study further demonstrates that HT, BPTB, TA, and Achilles allografts are each safe and effective allograft choices for primary ACLR in cohorts of patients older than 23 years who are not elite athletes. However, it is important to note that our systematic review does not compare patient outcomes and complications with allografts versus autografts; rather, it suggests that if an allograft is used in patients older than 23 years who are not high-level athletes, graft choice does not have a substantial impact on outcomes.

A 2015 systematic review and meta-analysis by Wasserstein et al.[32] including 788 patients with a mean age of 21.7 years across 7 studies found that patients who received tibialis, BPTB, and Achilles allografts experienced a 25.0% failure rate whereas patients who received BPTB and quadriceps tendon autografts experienced a 9.6% failure rate. The relative risk of graft failure of autografts compared with allografts was calculated to be 0.36, with a significantly low *P* value. The authors concluded that the comparative risk of graft rupture associated with allograft use compared with autograft use was high enough to caution

orthopaedic surgeons regarding the use of allografts for ACLR in a young, active population.[32]

In this study, there were no clinically relevant differences in IKDC, Lysholm, or Tegner scores at minimum 18-month follow-up or differences in preoperative and postoperative scores among patients receiving HT, BPTB, TA, and Achilles allografts. Additionally, although each study included in this systematic review had a sufficiently low risk of bias for inclusion, there was objectively high heterogeneity among the included studies as measured by $I^2$ values of 96.04% for the Lysholm score and 97.56% for the IKDC score. As a result of this high heterogeneity, we opted not to perform a meta-analysis and not to pool data.

In a 2010 systematic review including 31 studies that evaluated BPTB and HT allografts, Foster et al.[33] concluded that no individual graft source was clearly superior and that choice of graft tissue should be based on the patient's demographic characteristics and athletic ability and the preference of the surgeon. Our study revealed similar PROMs including IKDC, Lysholm, and Tegner scores for patients who received HT, BPTB, TA, and Achilles allografts. However, all of these PROMs had smaller standard deviations at final follow-up for BPTB allografts compared with soft-tissue grafts, possibly indicating a more consistent end result at final short-term follow-up. Our study found that with BPTB grafts, there was greater uniformity in postoperative IKDC and Tegner scores across studies, with much smaller standard deviations, indicating more predictable improvement than some of the other graft options. This may be attributable to a greater number of studies and subsequently greater sample size of patients with BPTB allografts; however, it may also indicate a more predictable result with BPTB allografts. A 2023 retrospective study by Sylvia et al.[34] reported patients receiving soft-tissue allografts for primary ACLR to have a median IKDC score of 83.9, which falls within the ranges of means reported by all cohorts in our study. A 2009 prospective randomized study evaluating 99 total patients, 66 of whom received BPTB allografts, found mean IKDC scores of 84 to 89, mean Lysholm scores of 87 to 91, and mean Tegner scores of 7.0 to 7.5 for nonirradiated and irradiated allografts.[35] These values all fall within the range of IKDC, Lysholm, and Tegner scores reported by the articles that met the inclusion criteria for our study.

Functional outcomes were included by studies for each of the 4 cohorts in this review. Measurements of side-to-side differences in anterior translation of the tibia measured by KT-1000 arthrometer showed overlapping ranges for the HT, BPTB, TA, and Achilles allograft cohorts. A 2003 study by Chang et al.[36] evaluating 46 patients undergoing ACLR with BPTB allografts found a side-to-side difference of 1.2 mm, which falls within the ranges of all KT-1000 values for the 4 graft types included in our study. Similarly, in a 2012 retrospective cohort study by Ghodadra et al.[37] that evaluated 106 patients receiving BPTB allografts for primary single-incision ACLR, the postoperative side-to-side difference was found to have mean values ranging from 0.4 to 0.5 mm, with standard errors of the mean ranging from 1.7 to 1.8 mm, which is in line with the values reported by the studies in our systematic review.

Each of the included studies reported a failure rate ranging from 0% to 25.5%, with the study by O'Brien et al.[27] reporting a failure rate of 65% for its BPTB cohort. Previous studies have reported failure rates for the use of allografts in ACLR to range from 5.6%[28] to 25.5%,[38] which is in line with the values obtained from our systematic review. The study by O'Brien et al. had a retrospective design and included only 20 total patients in each of its BPTB and TA cohorts. Their study did have the youngest patients of any of the included studies, with a mean age of 23.9 years in its BPTB cohort. Previous studies have determined that adherence to slower rehabilitation protocols for younger ACLR patients is crucial to preventing allograft failure and that failure rates generally tend to decrease with increased age among allograft patients.[7,16] The high outlier failure rate of the BPTB cohort of O'Brien et al. can be explained by the relatively young mean age of their included patients of 23.9 years and the inherently high variability associated with their small sample size of 20 patients.

Decisions regarding allograft choice should be tailored to individual patient characteristics and surgeon preference. Furthermore, more primary studies, systematic reviews, and meta-analyses are required to further understand outcomes in patients who undergo ACLR with different types of allografts. In particular, there is a paucity of data evaluating patient outcomes after ACLR with quadriceps tendon allograft.

## Limitations

This study is not without limitations. First, the study is limited by the relatively small sample sizes of the included studies, differences in surgical techniques, differences in graft sterilization, and indications for specific allografts, as well as the retrospective nature of many of the studies. In particular, no studies that met the inclusion criteria evaluated quadriceps tendon allografts, which could not be accounted for in our systematic review. Second, PROs were not routinely reported preoperatively in all studies, so improvement at final follow-up could not be determined. Furthermore, although the mean follow-up time was greater than 2 years across all included patient cohorts, the minimum follow-up time in the TA cohort was 18 months. In addition, clinically significant outcome measures including the minimal clinically important

difference, patient acceptable symptomatic state, and substantial clinical benefit were not reported in any included study, which limits the interpretation of the PRO data provided in each study. Additionally, numerous studies included in this systematic review were published by the same group of authors, which means that it is likely that some patients included in our study were counted more than once. Finally, we were unable to further stratify our data based on factors such as whether the allografts were irradiated or nonirradiated and whether the patients were athletes, both of which can affect rerupture and complication rates.

## Conclusions

Primary ACLR with allografts in patients older than 23 years is safe and effective with few differences in PROs, postoperative function, and graft failure rates among graft options.

## Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: J.C. is a board or committee member of American Orthopaedic Society for Sports Medicine, Arthroscopy Association of North America, and International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine; is a paid consultant for Arthrex, ConMed Linvatec, Ossur, RTI Surgical, Smith & Nephew, and Vericel; receives hospitality payments from Breg, DePuy Synthes Sales, Joint Restoration Foundation, Medical Device Business Services, Pacira Pharmaceuticals, SI-Bone, and Vericel; receives educational support from Medwest Associates; and is a paid presenter or speaker for Smith & Nephew. N.N.V. receives hospitality payments from Abbott Laboratories, Axonics, Boston Scientific, Foundation Fusion Solutions, IBSA Pharma, Nalu Medical, Nevro, Orthofix Medical, Pacira Pharmaceuticals, Relievant Medsystems, Salix Pharmaceuticals, Vericel, and Vertos Medical; is a board or committee member of American Orthopaedic Society for Sports Medicine, American Shoulder and Elbow Surgeons, and Arthroscopy Association of North America; receives intellectual property royalties from Arthrex, Graymont Professional Products IP, Smith & Nephew, and Stryker; receives research support from Arthrex, Breg, Ossur, Smith & Nephew, and Stryker; is a paid consultant for Medacta USA and Stryker; receives educational support from Medwest Associates; is on the editorial or governing board of SLACK; and receives travel and lodging payments from Spinal Simplicity. All other authors (U.D., J.B.V-E., H.S., E.J.C., F.G-V., M.C., C.G., A.M.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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