

Thirty-Year Experience With ACL Reconstruction Using Patellar Tendon

A Critical Evaluation of Revision and Reoperation

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Background: During the preoperative discussion prior to anterior cruciate ligament reconstruction (ACLR), patients are often interested in data regarding rates of revision reconstruction, reoperation, concomitant pathologic changes, and future contralateral ACL injury.

Purpose: To analyze a single surgeon's experience with primary and revision ACLR over a 30-year interval, focusing on incidence and risk factors for revision and reoperation.

Study Design: Case series; Level of evidence, 4.

Methods: Patients who underwent ACLR from 1986 to 2016 were identified from a prospectively maintained database. Covariates of interest included age, sex, time, and graft selection. Outcomes of interest included revision and reoperation rates.

Results: A total of 2450 ACLRs (mean patient age, 29 years; 58% male) were reviewed. Among primary ACLRs performed ($n = 2225$), 68% entailed bone-patellar tendon-bone (BTB) autograft and 30% entailed BTB allograft. Patients undergoing ACLR with autograft and allograft had a mean age of 22 and 37 years, respectively. The rate of revision ACLR was 1.8% and 3.5% for primary and revision cases, respectively. An increased rate of revision was noted among females compared with males (2.6% vs 1.2%) and among allografts compared with autografts (2.7% vs 1.3%). Low-dose irradiation did not affect allograft revision rates. The nonrevision reoperation rate following primary ACLR was 12%. The nonrevision reoperation rate was lower among primary cases reconstructed with allograft than autograft (9% vs 13%). Seventeen percent of cases involved concomitant meniscal repair and, among these, 13% required revision meniscal surgery. The rate of contralateral ACLR was 5.3%

Conclusion: This information is useful in the informed consent process, for perioperative decision making regarding graft choice, and for identifying patients who are at risk for injuring the uninjured knee.

Keywords: anterior cruciate ligament; revision rate; reoperation rate; allograft; contralateral

Anterior cruciate ligament (ACL) reconstruction (ACLR) is one of the most commonly and successfully performed procedures in orthopaedic sports medicine, with 60% to 80%

rates of return to play among high-level competitive athletes^{4,5,24-26,28,31} and clinical failure rates between 3% and 6%.^{6,13,15,17,18,29,30} Although rates of return to play and clinical failure are the most broadly published benchmarks used to gauge the success of ACLR, these numbers fail to tell the complete story. During the preoperative discussion prior to ACLR, patients are often interested in data regarding incidence and risk factors for revision, reoperation, concomitant abnormality, and future contralateral ACL injury. This information is also useful to surgeons in guiding graft choice and surgical technique.

Given the difficulty in attaining sufficient volume to determine accurate reoperation rates, the incidence of reoperation following ACLR has been infrequently studied in the literature, and the majority of the data available are derived from multicenter case series and state or insurance-network registry studies.^{7,12,20,33,35} Although multicenter consortiums and registries offer the benefit of

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large numbers for subgroup analysis, the data in these studies are often derived from a large number of surgeons (hundreds in some cases)^{7,20} with a large variation in surgical indications, surgical technique, and graft choice.

The purpose of this study was to describe and analyze a single surgeon's experience with primary and revision single-bundle ACLR, with a specific emphasis on incidence and risk factors for reoperation and revision. Using a prospectively maintained database, we aimed to determine (1) the demographics of patients undergoing primary and revision ACLR; (2) patterns of graft use over the 30-year interval; (3) the rate of concomitant procedures performed (meniscal, chondral, and multiligamentous); (4) the impact of patient sex and age on the rate of contralateral ACL injuries; (5) the impact of graft selection, patient sex, and patient age on clinical failure and reoperation rates; and (6) differences between primary and revision ACLR regarding rate of revision, rate of reoperation, and success of meniscal repair. We hypothesized that (1) the revision ACL population would be older and would have a greater proportion of female patients compared with the primary ACL population; (2) use of allograft would increase steadily over time; (3) meniscal repair in association with ACL injury would fail at a lower rate than historical data regarding isolated meniscal repairs; (4) younger patients and women would be more likely to undergo contralateral ACLR; (5) failure rates would be increased in younger patients, females, and revision reconstructions; and (6) revision reconstruction would be associated with increased risk of revision, reoperation, and failed meniscal repair compared with primary reconstruction.

METHODS

This was a retrospective evaluation of the senior author's (B.R.B.) prospectively maintained surgical database for all patients who underwent primary or revision ACLR from September 1986 to May 2016. Follow-up was available only for patients who sought subsequent surgery with the senior surgeon or who presented with a contralateral ACL injury. Cohorts have been reported in previously published clinical studies of minimum 2-year follow-up evaluations of 2-incision ACLR, single-incision ACLR, minimum 2-year endoscopic ACLR with nonirradiated patellar tendon allograft, midterm 5- to 9-year follow-up evaluation of autograft 2-incision bone–patellar tendon–bone (BTB) ACLR, results of ACLR in workers' compensation patients, and ACLR in patients older than 35 years.^{1-3,27,36}

Surgical Technique

Between 1986 and October 1991, a 2-incision, arthroscopically assisted, single-bundle ACLR technique was used, and since October 1991, a single-bundle, transtibial technique has been used with either BTB autograft or allograft tissue. Multiple strategies have evolved over time to achieve optimal femoral tunnel positioning, including a more proximal and medial tibial starting point and use of an accessory inferolateral transpatellar portal for oblique

placement of the tibial aiming device. These modifications facilitate creation of an obliquely oriented tibial tunnel, which permits placement of the femoral tunnel low on the lateral wall of the intercondylar notch. Metal interference screws were used for fixation in both the femur and tibia. Grafts were tensioned with an axial load in extension or hyperextension. An accelerated postoperative rehabilitation program with full range of motion and full weightbearing has been used since 1990; prior to this, weightbearing and terminal extension were limited until 6 weeks postoperatively.

Statistical Analysis

Data were extracted from the database and analyzed by an independent analyst. Descriptive statistics were used to describe the cohort undergoing primary and revision ACLR. The Student *t* test and analysis of variance (ANOVA) were used for continuous data and to compare outcomes over 5-year incremental time periods, respectively. The Fisher exact and chi-square tests were used for categorical data (patient sex, graft choice, rate of revision ACLR, and rate of reoperation). An alpha level of .05 was determined to be of statistical significance.

RESULTS

Between September 1986 and May 2016, 2450 ACLRs were performed in 2276 patients. Among these cases, 2225 (91%) were primary reconstructions and 225 (9%) involved revision ligament reconstruction. Of the revisions performed, 40 patients re-presented with a failed ACLR and underwent a revision ACLR; 185 patients transferred care to the senior surgeon. Of the revisions, 23 (10%) were repeat revisions; 7 of these were failures of the senior surgeon's revision procedure. Two-incision ACLR was performed in 214 cases, and single-incision, arthroscopically assisted, transtibial reconstruction was performed in 2236 cases.

Patient Demographics

Demographic data regarding patient age, sex, and laterality for patients undergoing primary, revision, and re-revision ACLR are available in Table 1. No differences were found in age or sex distribution among patients treated with primary and revision ACLR; however, women trended toward being more likely to undergo re-revision ACLR than men ($P = .12$).

Follow-up

Follow-up data were available only for patients who sought subsequent surgery with the senior surgeon or presented with contralateral ACL injury. The mean follow-up for all such patients who had primary ACLR was 15.7 years (range, 0.8-29.8 years; SD, 7.9 years). Mean follow-up was 17.7 years (range, 0.8-29.8 years; SD, 7.6 years) for the primary cases treated with autograft and 9.4 years (range, 1.2-23.0 years; SD, 5.0 years) for primary cases treated with

TABLE 1
Demographic Data for Patients Undergoing Primary, Revision, and Re-revision Anterior Cruciate Ligament Reconstruction

	No. of Cases	Age, y			Sex, Male:Female, n (% Male)	Affected Side, % Right Knee
		Mean	SD	Range		
Primary	2225	29.3	15.1	11-71	1296:929 (58)	50
Revision	225	29.2	9.0	14-52	124:101 (55)	46
Re-revision	23	29.2	7.9	18-50	9:14 (39)	48

TABLE 2
Graft Use for Primary Anterior Cruciate Ligament Reconstruction^a

Graft Choice	n	Age, y	Sex, Male:Female, n
BTB autograft	1510	21.7	933:577
BTB allograft	674	37.3	347:327
HS autograft	25	20.7	7:18
HS allograft	16	13.3	10:6

^aBTB, bone–patellar tendon–bone; HS, hamstring.

allograft. Mean follow-up for patients undergoing revision ACLR was 11.4 years (range, 1.8-18.3 years; SD, 6.3 years).

Graft Choice

Among primary ACLR cases, 68% (n = 1510) involved a BTB autograft, while 30% (n = 674) were reconstructions with a BTB allograft. Among allograft ACLRs, 674 cases (98%) entailed a central-third BTB graft; 119 patients had a nonirradiated allograft (prior to September 2003) and 555 patients had allografts that were processed and sterilized with low-dose (1.2 Mrad) irradiation (September 2003 and beyond) from a single American Association of Tissue Banks (AATB)–certified tissue bank (AlloSource). The graft breakdown for primary ACLR is available in Table 2. Hamstring (HS) autograft was predominantly used in high school females, whereas the use of HS allograft was generally reserved for petite, prepubescent, skeletally immature patients.

Allograft tissue use increased over time from 1% of all primary cases in 1986-1991 to 23% (1997-2001) and, most recently, to 53% (2012-2016) (P < .001). For the past 15 years, 50% of patients with primary ACLR were treated with an allograft BTB graft, and over 30 years, 30% of patients were primarily treated with an allograft BTB reconstruction. Five-year trends for allograft use over time are illustrated in Figure 1. The use of allograft tissue for primary ACLR also increased with patient age, as illustrated in Figure 2 (P < .001).

Among patients undergoing revision ACLR, 76% (n = 170) were treated with central-third BTB allograft and 21% (n = 48) had a BTB autograft; 2 patients had contralateral BTB autograft, 1 patient had HS autograft, 1 patient had a quadriceps tendon autograft, and 3 patients had a tendo-Achilles allograft. Hemi-BTB allografts were not used. The graft breakdown for revision ACLR is available in Table 3.

Concomitant Procedures

Of the 2450 ACLRs, 35 (1.4%) were performed as part of a multiligamentous reconstruction. Among these, 4 were classified as knee dislocation (KD) III injuries, 6 as KD II injuries, and 25 as KD I injuries. Fourteen involved posterolateral corner reconstruction, 12 medial collateral ligament (MCL) reconstruction, 10 posterior cruciate ligament (PCL) reconstruction, and 2 MCL repair. Meniscal abnormality was addressed surgically in 43% of cases (n = 1060; 976 in primaries; 84 in revisions). Among these, the medial meniscus was involved in 476 cases (45%), the lateral meniscus in 351 cases (33%), and both medial and lateral meniscus in 223 cases (21%). Of note, tears involving the medial meniscus were amenable to repair significantly more commonly than those involving the lateral meniscus (47% vs 25%, P < .001). A trend was noted toward more common meniscal abnormality in primary cases than revision cases (43% vs 37%, P = .08). Among all cases of ACLR, 424 cases (17%) included concomitant meniscal repair. Among meniscal repairs, 250 were performed in an open fashion (inside-out or outside-in) and 174 were performed with an all-inside device (Fast-Fix; Smith & Nephew). Meniscal repair was performed more commonly for tears noted during primary ACLR than those observed during revision ACLR (41% vs 31%, P = .01). Microfracture was performed in 25 cases (1%): 17 were performed on the medial femoral condyle, 7 were performed on the lateral femoral condyle, and 1 was performed on both the medial and lateral femoral condyle.

Contralateral ACL Reconstruction

Subsequent contralateral ACLR was performed in 5.3% of patients (n = 111; 56 females, 55 males). Females were more likely to undergo contralateral reconstruction than were males (6.4% vs 4.4%, P = .048). Contralateral ACLR was performed at a mean of 41 months after initial ACLR (range, 0-161 months; SD, 42 months). A trend was found toward decreased time to contralateral reconstruction in females compared with males (34 vs 48 months, P = .08). The mean ages at initial and contralateral reconstruction were 21.9 years (range, 12-55 years; SD, 10.2 years) and 26.5 years (range, 15-62 years; SD, 11.4 years), respectively. Among patients who underwent bilateral ACLR, females were significantly younger at initial ACLR (19.8 vs 23.7 years; P = .003) and at contralateral ACLR (23.8 vs 29.6 years, P < .001). Among patients who were younger than 20 years at the time of initial reconstruction, 8.7%

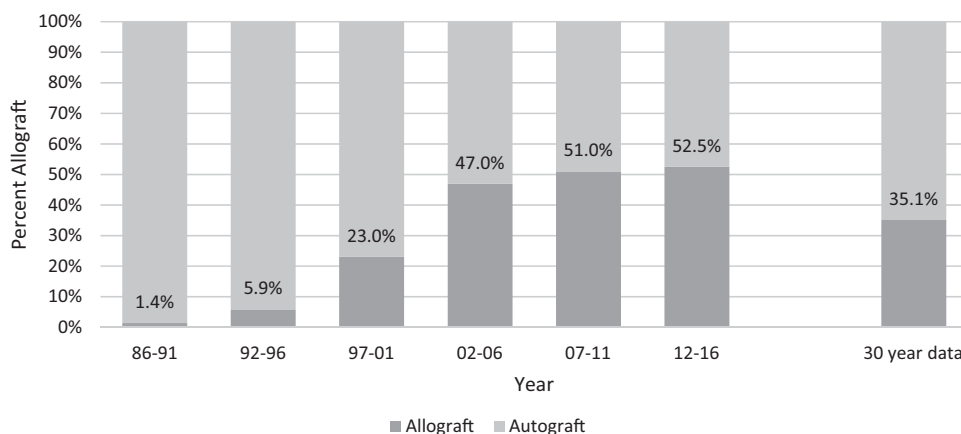


Figure 1. Trends in allograft use over time.

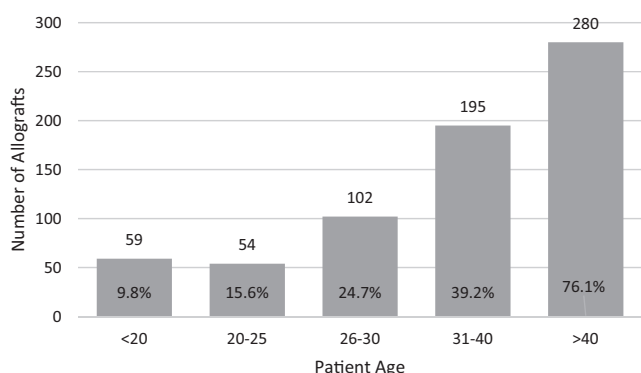


Figure 2. Number of allografts used for primary anterior cruciate ligament reconstruction (ACLR) in each age cohort (percentages reflect the proportion of ACLRs in each age cohort reconstructed with allograft).

TABLE 3
Graft Use for Revision Anterior Cruciate Ligament Reconstruction^a

Graft Choice	n	Age, y	Sex, Male:Female, n
BTB allograft	170	30.6	81:89
BTB autograft	48	23.8	19:29
Achilles allograft	3	32	1:2
Contralateral BTB autograft	2	21.5	1:1
Quadriceps tendon autograft	1	34	1:0
HS autograft	1	44	1:0

^aBTB, bone–patellar tendon–bone; HS, hamstring.

underwent contralateral reconstruction, compared with just 3.6% of those 20 years or older ($P < .001$). Among patients undergoing bilateral ACLR, 83% (92/111) received the same graft for initial and contralateral reconstruction. Among those who received different grafts, BTB autograft followed by BTB allograft was used in 12 patients, and HS allograft followed by BTB autograft was used in 4 patients. This was predominantly based on patient age

or reduced athletic demand. The interval from initial to contralateral reconstruction was significantly longer in those reconstructed with different grafts than those reconstructed with the same graft (80 vs 33 months, $P < .001$). Most of these cases involved either (1) a patient who underwent initial ACLR with HS allograft during skeletal immaturity and later underwent reconstruction with BTB autograft or (2) a patient who underwent initial reconstruction with BTB autograft and, after a decrease in level of demand, elected to undergo contralateral reconstruction with a BTB allograft.

Revision and Re-revision ACL Reconstruction

The rate of revision ACLR was 1.8% ($n = 40/2225$) for all primary cases. The mean ages at primary and revision ligament reconstruction were 24.3 years (range, 12-48 years; SD, 9.6 years) and 29.2 years (range, 15-51 years; SD, 10.2 years), respectively. The mean time to revision ACLR was 54 months (range, 3-176 months; SD, 46.7 months). Revision rates remained stable over time between 1986 and 2016 ($P = .08$). Failure was noted in 2.9% of patients who were 20 years or younger, 1.4% of patients age 21 to 25, 1.5% of patients age 26 to 30, 1.6% of patients age 31 to 40, and 0.8% of patients older than 40 (Figure 3). A significant difference in revision was noted in the group 20 years or younger compared with the remainder of the cohort ($P = .027$). Female patients were more likely to undergo revision ACLR than were male patients (2.6% [24/929] vs 1.2% [16/1296], $P = .02$). Patients undergoing reconstruction with BTB allograft were more likely to undergo revision than those with BTB autograft. The differences in revision rate between autograft and allograft were most marked in patients 30 years or younger (1.5% vs 5.1%, $P = .001$) (Figure 4). No difference was found between autograft and allograft with regard to interval from primary reconstruction to revision (56 vs 52 months, $P = .80$) (Figure 5). Among patients undergoing allograft ACLR, no differences in revision rate were found between patients treated with nonirradiated patellar grafts and those treated with low-dose irradiated grafts (4.2% [5/119] vs 2.3%

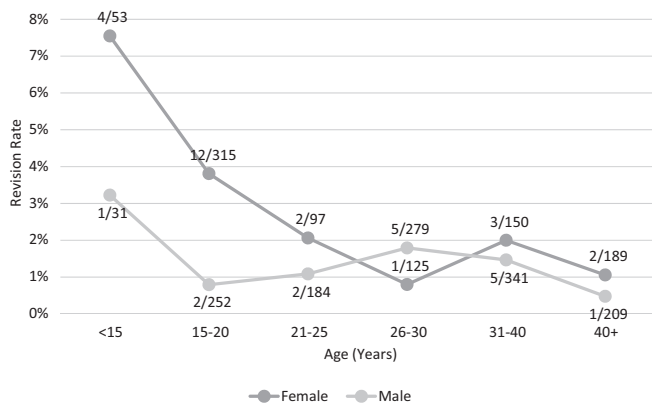


Figure 3. Rate of revision anterior cruciate ligament reconstruction as a product of age and sex. The most dramatic differences in revision rate between men and women were noted in patients 20 years or younger.

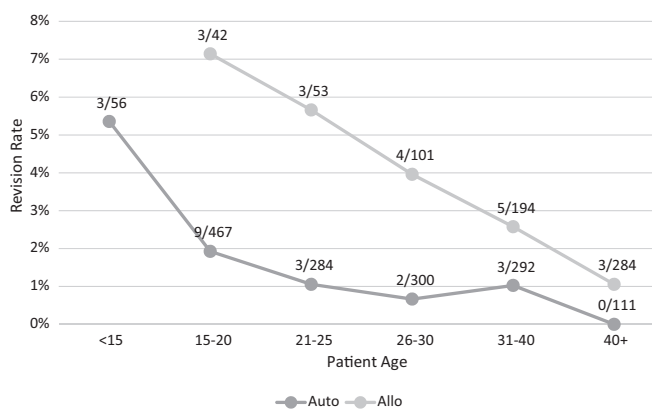


Figure 4. Rate of revision anterior cruciate ligament reconstruction as a product of age and graft choice. The most dramatic differences in revision rate between autograft and allograft were seen in patients 30 years or younger.

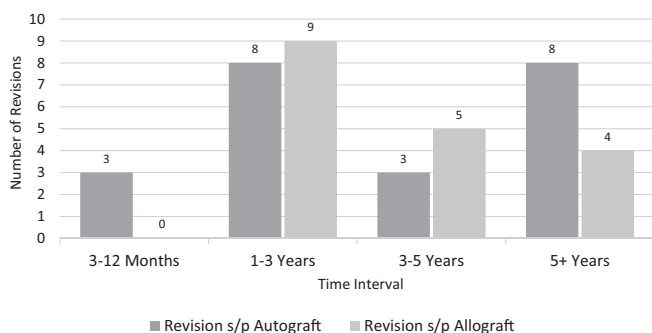


Figure 5. Interval to revision after failed autograft and allograft anterior cruciate ligament reconstruction. s/p, status post.

[13/555], $P = .34$). Among the 40 failed primary cases, 20 patients underwent primary reconstruction with BTB autograft, 18 with BTB allograft, 1 with HS allograft, and 1 with HS autograft. The re-revision rate of patients who

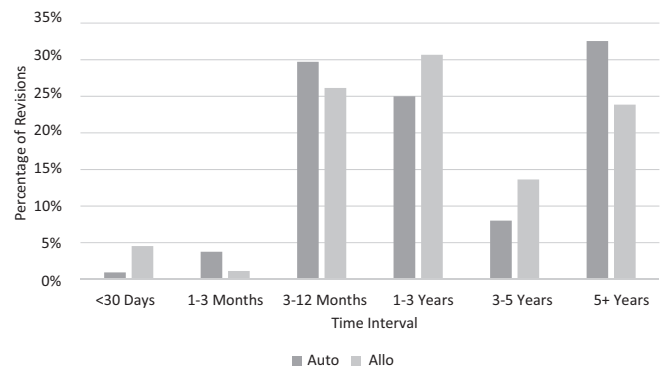


Figure 6. Proportion of reoperations following autograft and allograft reconstruction occurring at each postoperative time interval.

underwent revision ACLR was 3.1% ($n = 7/225$). All failed revision cases were BTB allograft. The mean age of patients at the time of the primary revision procedure was 26.1 years (range, 18-44 years), and the mean time to re-revision surgery was 35 months (range, 11-65 months). Four of the 7 re-revision cases were female patients.

Reoperation

The overall nonrevision reoperation rate for any reason was 12.2% ($n = 300$), with follow-up to 30 years postoperatively. The rate of reoperation within 5 years of primary ACLR was 8.5% ($n = 209$). No difference in reoperation rate was found between primary and revision reconstruction (12% [$n = 268$] vs 14% [$n = 32$], $P = .4$). However, a trend was noted toward an increased 1-year reoperation rate for revision ACLR compared with primary ACLR (6.2% [$n = 14$] vs 3.9% [$n = 87$], $P = .096$). The nonrevision reoperation rate was lower for primary cases reconstructed with allograft compared with autograft ($P = .004$) (9.3% [$n = 64$] vs 13.3% [$n = 204$], $P = .004$). Reoperation occurred at a mean 49.4 months (range, 0.5-316 months; SD, 58.7 months) from the time of primary ACLR. The mean \pm SD interval to reoperation for allografts and autografts was 37.4 ± 40.9 and 54.4 ± 64.3 months, respectively ($P = .028$) (Figure 6).

The indications for reoperation are illustrated in Figure 7. The most common indications for repeat surgery were new meniscal tears ($n = 81$; 3.3%), failed meniscal repair ($n = 57$; 2.3%), arthrofibrosis ($n = 57$; 2.3%), painful hardware ($n = 18$; 0.7%), degenerative joint disease ($n = 16$; 0.7%), loose body removal ($n = 11$; 0.4%), and infection ($n = 10$; 0.4%). Time intervals to reoperation for the most common causes for reoperation are displayed in Figure 8.

New Meniscal Tear

Reoperation for a new meniscal tear was performed at an average of 71 months (range, 4-265 months; SD, 61 months) postoperatively, and 62% of procedures were performed more than 3 years after reconstruction.

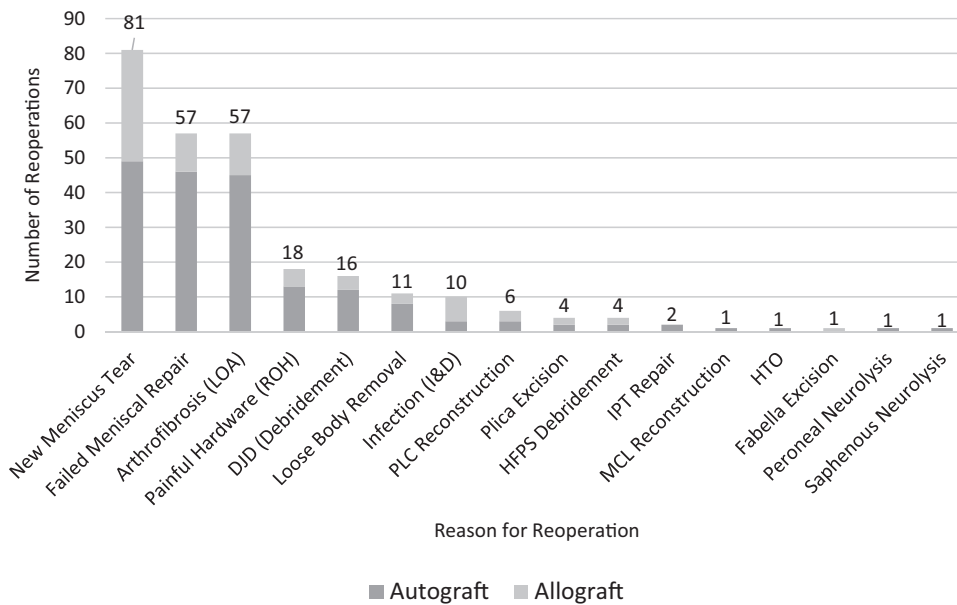


Figure 7. Reoperation following primary or revision anterior cruciate ligament reconstruction. Of note, this is not a comprehensive list with 29 additional reoperations performed for a variety of other reasons. DJD, degenerative joint disease; HFPS, hypertrophic fat pad syndrome; HTO, high tibial osteotomy; I&D, irrigation and debridement; IPT, infrapatellar tendon; LOA, lysis of adhesions; MCL, medial collateral ligament; PLC, posterolateral corner; ROH, removal of hardware.

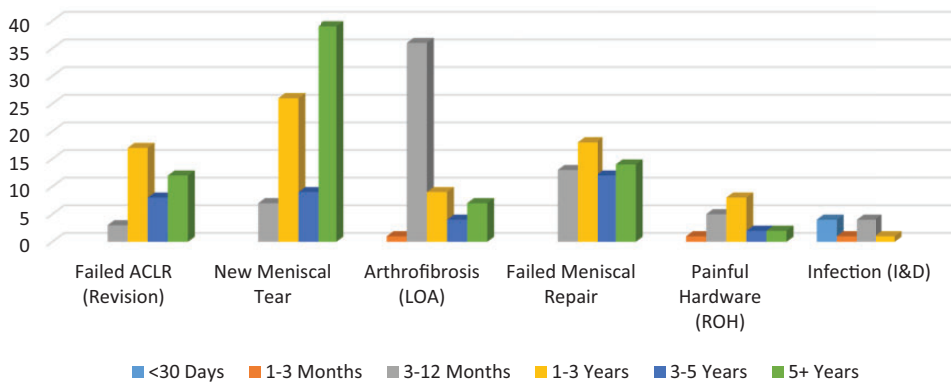


Figure 8. Interval to reoperation for the most common causes of reoperation. ACLR, anterior cruciate ligament reconstruction; I&D, irrigation and debridement; LOA, lysis of adhesions; ROH, removal of hardware.

Arthrofibrosis

Lysis of adhesions for arthrofibrosis was performed at an average of 30 months (range, 2-236 months; SD, 51 months) postoperatively, and 65% of procedures were performed within 1 year of reconstruction. A higher rate of reoperation for arthrofibrosis was noted among patients who underwent autograft reconstruction than among those who underwent allograft reconstruction (2.8% vs 1.4%, *P* = .03). Two patients required repeat lysis of adhesions for recalcitrant arthrofibrosis. Patient sex was not a risk factor for lysis of adhesions; lysis was performed in 2.4% of male patients with ACLR and 2.2% of female patients with ACLR (*P* = .79).

Failed Meniscal Repair

Among the 424 meniscal repairs performed, 57 (13%) required revision meniscal surgery at a mean of 37 months (SD, 32 months) after reconstruction. The overall rate of revision meniscal surgery following meniscal repair at the time of ACLR was 15% (n = 46) in patients undergoing autograft ACLR and 10% (n = 11) in patients undergoing allograft ACLR (*P* = .257). No difference was found in the rate of failed meniscal repair between primary and revision ACLR (14% [57/398] vs 12% [3/26]; *P* = .93). No difference in failure rate was noted between those procedures performed with an all-inside device and those performed in an open fashion (12% [21/174] vs 14% [36/250], *P* = .49).

Painful Hardware

Reoperation for painful hardware was performed at an average of 21 months (SD, 20 months) postoperatively. Among the 18 patients requiring removal of painful hardware, 13 had undergone reconstruction with BTB autograft, 2 with BTB allograft, 2 with HS autograft, and 1 with HS allograft. All cases involved painful tibial hardware. Patient sex was not a risk factor for hardware removal, as this procedure was performed in 0.7% of male patients and 0.8% of female patients undergoing ACLR ($P = .84$).

Infection

An irrigation and debridement procedure was performed in 5 patients for superficial infection and in 5 patients for deep infection (ie, septic arthritis). Reoperation for infection was performed at an average of 5.2 months postoperatively (range, 2 weeks to 12 months; SD, 5.5 months). Irrigation and debridement constituted 4 of the 6 reoperations performed within 1 month of reconstruction. Two patients required repeat irrigation and debridement. A higher rate of reoperation for infection was found among patients who underwent allograft reconstruction than among those who underwent autograft reconstruction (0.8% vs 0.1%, $P = .01$). All grafts and hardware were maintained.

30- and 90-Day Reoperation

Six patients (0.2%) underwent reoperation within 30 days of surgery. As previously mentioned, 4 of these operations entailed irrigation and debridement for infection. Two additional patients underwent reoperation within a month of surgery: 1 patient for repair of a traumatic infrapatellar tendon rupture and 1 patient for removal of a broken intra-articular nitinol guide pin noted on the first postoperative radiograph. Fifteen patients (0.6%) underwent reoperation within 90 days of surgery (including the aforementioned 6 patients within 30 days). Among the 9 reoperations performed between 30 and 90 days after reconstruction, 5 entailed lysis of adhesions for arthrofibrosis, 1 removal of hardware, 1 loose body removal, 1 irrigation and debridement for septic arthritis, and 1 wound exploration for saphenous neuritis.

DISCUSSION

The current study used a prospectively maintained administrative database, developed and maintained by a single senior surgeon, to describe the demographics and pertinent surgical-based outcomes of a consecutive cohort of 2276 patients who underwent primary or revision ACLR over a 30-year period. The value of the information generated from the current descriptive analysis relates to the long-term follow-up of patients from the practice of a single provider where the surgical techniques of choice (2-incision or 1-incision ACLR with BTB) have remained consistent over time. The focus of this study has been on the incidence and

risk factors for reoperation, revision, concomitant abnormality, and future contralateral ACL injury after primary and revision ACLR.

In this series, the observed revision rates with primary and revision ACLR were 1.8% and 3.5%, respectively. The average interval to follow-up in this series was 15.7 years (SD, 7.9 years) and 11.4 years (SD, 6.3 years) for primary and revision ACLR, respectively, which provides a representation of the natural history after ACLR when performed by a single individual with little variation in surgical technique. Lengths of follow-up and revision rates vary widely in the literature. Two systematic reviews on primary ACLR demonstrated an objective failure rate of approximately 6% at variable follow-up periods.^{18,37} In 2 community-based registries in the United States and Norway, the rate of revision surgery was 0.9% and 1.6% at less than 3-year follow-up, respectively.²² A study that analyzed the national Danish registry showed that revision rates after primary ACLR ($n = 12,193$) and re-revision rates ($n = 1099$) were 4.1% and 5.4%, respectively, at 5 years.¹⁹ In a comparison of 3 international cohorts of revision ACLR procedures, namely the Multicenter ACL Revision Study (MARS) database (United States), Norwegian Cruciate Ligament Register (NKLR) database (Norway), and Société Française d'Arthroscopie (SFA) database (France), revision rates were highly variable in different regions of the world.^{18,21,37} Our observed revision rate for both primary and revision cases has remained similar over the past 5 years, and it is comparable to the rates reported in the American literature. Frank and colleagues¹⁰ reported a revision rate of 1.8% among 1944 primary ACLRs performed at a single institution between 2002 and 2009. Ponce and colleagues²⁸ reported an institutional revision rate of 2.3% among 2965 ACLRs performed between 2001 and 2008.

A significant difference in revision rate was found between patients undergoing reconstruction with BTB autograft versus BTB allograft (1.3% [23/511] vs 2.7% [18/674], $P = .03$). This finding differs from our previous finding that revision rates were not significantly different between autograft and allograft patients.⁶ One may argue whether this is a clinically meaningful difference. Although the revision rate was twofold, the success rate with allograft is extremely high, particularly in patients older than 30 years. The allograft revision rate among patients 30 years and younger was 5.1% compared with 1.7% in patients older than 30. Allografts were used very selectively in patients younger than 25, often due to extenuating circumstances regarding petite stature, rehabilitation concerns, or strong patient preference. In this study, allografts were obtained from a single tissue bank that was AATB certified, and central one-third BTB grafts were used. Variations in tissue banks, grafts, sterilization methods, and levels of radiation are factors that have been implicated in conflicting reports regarding allograft outcomes.

The literature is replete with conflicting results with respect to failure rates after ACLR with various graft choices. Foster et al,⁹ in their review of level 1 and 2 studies, calculated graft failure rates of 4.7% and 8.2% for autograft and allograft tissues, respectively.^{13,15,17,18,22,29,30} They

concluded that there was no statistical difference in these failure rates. Likewise, Carey et al⁵ found no significant difference in failure rates in their systematic review of level 3 and 4 studies of various graft selections.^{7,8,12,19,20,33,35} However, an increasing body of evidence suggests that autograft outperforms allograft ACLR in the young, active patient.^{7,15,16,20,23} Our results from the high-volume practice of a single surgeon are consistent with the current literature trends showing higher failure rates with an allograft, particularly in patients younger than 25 years. The increase in allograft use in recent years in our practice is due to an overall older patient cohort as well as the senior author's low revision rates, which result in an increased confidence with this tissue use.

Over time, the number of cases in which reconstruction was performed with allograft tissue increased in this surgeon's practice. Although only 1% of ACLRs were performed with allograft tissue from 1986 to 1991, over the ensuing 5-year time increments these rates increased to 5.9%, 23%, 47%, 51%, and 52.5%. The senior surgeon chose to expand indications of this graft type over time based on several factors: clinical observations; KT-1000 arthrometer data demonstrating similar results between autograft and allograft BTB within the first year without any increase in laxity; an overall low rate of repeat revision within the first year (3/2250); and a clinical follow-up study performed at a minimum 2-year follow-up that demonstrated comparable stability, KT-1000 arthrometer results, failure, and subjective satisfaction results.^{1-3,11,27,36} Data from the Multicenter Orthopaedic Outcomes Network (MOON) study, one of the largest, prospectively collected, multicenter studies looking at ACLR outcomes and demographics, corroborated the successful use of allograft tissue in patients of appropriate age and activity level. The MOON study observed that although the graft failure rate was significantly higher in patients with an allograft ACLR, the failure rates converged dramatically after the age of 30. In their study, the failure rate in 14-year-olds was 6.6% for autograft and 22% for allograft constructs. In contrast, the authors found the failure rate to be significantly lower for older patients. In 40-year-olds, for instance, the failure rate for ACLR was 0.6% for autograft and 2.6% for allograft.^{14,18,37} As expected, the mean age for a patient treated with allograft reconstruction continues to be significantly higher than the age of patients treated with autograft in our practice. These findings emphasize the importance of patient selection when recommending graft choice; more consideration is now being given to allograft reconstruction for patients older than 30 whose activity levels are less demanding or who may have extenuating personal or professional constraints that favor use of an allograft.

In this study, when analyzing the database, we tabulated the incidence of all concomitant procedures. Thirty-five ACLRs were performed as part of a multiligamentous reconstruction. Fourteen involved posterolateral corner reconstruction, 12 MCL reconstruction, 10 PCL reconstruction, and 2 MCL repair. Meniscal abnormality was addressed during the ACLR in 43% of cases, with the medial meniscus being the most common. Likewise, medial meniscal tears were deemed amenable for repair more

commonly than those involving the lateral meniscus (47% vs 25%, $P < .001$). We found a trend toward more common meniscal abnormality in primary ACLR versus revision, although this did not reach statistical significance (43% vs 37%, $P = .08$). Overall, meniscal tears were determined to be amenable for repair more commonly in primary ACLR than in revision ACLR (18% vs 12%, $P = .014$). Meniscal abnormality was fairly common and was successfully addressed in most cases.

Microfracture was performed in 25 cases (1%); 17 were performed on the medial femoral condyle, 7 on the lateral femoral condyle, and 1 on both the medial and lateral femoral condyle. Tahami and Rad³⁴ compared isolated ACLR versus ACLR with concomitant high-grade chondral defect treated surgically. They found that patients with high-grade articular cartilage defects addressed at the time of ACLR had good long-term outcomes, with no difference compared with patients with isolated ACL tears. In our cohort, cartilage injuries were infrequently treated with surgery. Shelbourne et al,³² in their landmark study in 2003, demonstrated that the majority of articular cartilage defects noted during ACLR did not have implications for long-term outcomes, regardless of size. They also showed that the majority of patients had very few symptoms related to their articular cartilage defect. It is the practice of our senior surgeon to address articular cartilage defects during the time of ACLR on a case-by-case basis, with the majority being left untreated.

In the current study, the rate of reoperation for any reason (including revision ACLR) was 14.2% ($n = 347$). The most common indications for reoperation were new meniscal tears ($n = 81$; 3.3%), failed meniscal repair ($n = 57$; 2.3%), arthrofibrosis ($n = 57$; 2.3%), revision or re-revision (47), and painful hardware ($n = 18$; 0.7%). The reoperation rate for infection has been 0.4% ($n = 10$) over the 30-year period. Male sex has been identified by other authors as a risk factor for lysis of adhesions; however, this was not noted in the current study ($P = .79$). Similarly, female sex has been identified by other authors as a risk factor for hardware removal; however, we did not find that to be the case ($P = .84$), perhaps because we did not use extracortical fixation for our grafts.

We found a significantly higher nonrevision reoperation rate following primary ACLR with autograft (13.3%, $n = 204$) than with allograft (9.3%, $n = 64$) ($P = .004$). In our previous study, we attributed this finding to a lack of long-term follow-up. As the use of allograft for ACLR increases and long-term follow-up has become available for a larger percentage of these patients in the senior author's practice, it appears more likely that this finding represents a true difference in reoperation rates. The vast majority of reoperations in our study occurred within 5 years of surgery in both groups. One possible explanation for this difference is that autograft reconstructions tend to be performed in younger, more active patients at higher risk for subsequent injuries. Our observed reoperation rate of 8.5% within 5 years of primary ACLR is lower than rates reported in the literature. Hettrich et al¹³ described a 25% reoperation rate on the ipsilateral knee at 6-year follow-up in the MOON cohort. A 9.6% overall nonrevision reoperation rate at 24

to 114 months of follow-up was noted in a systematic review performed by Lewis et al¹⁸ in 2008. With regard to the success of concomitant meniscal repair, we observed a reoperation rate of 13% for revision meniscal surgery at a mean of 37 months (range, 4-116 months; SD, 32.2 months). The rate of revision meniscal surgery following meniscal repair at the time of ACLR was 15% (n = 46) in patients undergoing autograft ACLR and 10% (n = 11) in patients undergoing allograft (P = .257). Our reoperation rate following meniscal repair is consistent with the existing literature.

The use of an administrative single-surgeon database has inherent limitations. The most obvious limitation is the possibility of attrition bias. Our reoperation rates and other follow-up information are based on data collected for patients who returned for routine postoperative follow-up or for a subsequent injury. With the database used in this study, we were unable to identify the number of patients who may have moved to a different region of the country or who may have transitioned their follow-up care to another physician. Certainly, this may have led to an underestimation of the true rates of reoperation and revision ACLR. Nevertheless, the revision rates parallel our institutional revision rates, reported over a 6-year period, for several different graft types used among 4 surgeons in 1944 patients undergoing ACLR.¹⁰ Furthermore, this study does not provide information regarding the progression of arthritis or the need for osteotomy, partial knee arthroplasty, or total knee arthroplasty. One might criticize the inclusion of all patients in reoperation rate calculations, even those less than 2 years postoperatively as required in clinical follow-up studies. Including reoperations from postoperative day 1 allowed us to capture early meniscal repair failures, cases of arthrofibrosis, reoperations for infections, rare ACL failures within the first year, and reoperations for symptomatic arthrofibrosis. Furthermore, this allowed us to study 30- and 90-day reoperation rates, which are the topic of a subsequent manuscript. Our database consists of largely demographic data, diagnoses, and surgical procedures performed. We are unable to report clinical information such as mechanism of injury, activity level, body mass index, and patient-related outcome measures. Patient and surgeon factors that are unique to the academic tertiary-care referral practice of the senior surgeon may not reflect the general population undergoing ACLR. However, the information derived from a single surgeon's database that has been collected over a 30-year period with a consistent technique provides a high degree of internal validity with respect to the technical aspects of ACLR.

Finally, in an evolving era that will demand personal physician-reported outcomes, this database reflects important information that can be shared not only with patients regarding personal outcomes but also with insurers.

CONCLUSION

During the preoperative discussion prior to ACLR, patients are often interested in data regarding incidence and risk factors for reoperation, revision, concomitant abnormality,

and future contralateral ACL injury. This information is also useful to surgeons in guiding graft choice and surgical technique. Our study provides useful data in a long-term cohort that describes the incidence of various causes of failure and revision surgery after ACLR. Likewise, our study provides useful data for patients planning to undergo revision ACLR. The revision rates for primary and revision ACL surgery were low in general for both BTB autograft and allograft, and we did not note a significant change when compared with our reported 25-year experience. As noted by other studies, the use of allograft must be recommended with caution, especially in patients younger than 25 years.

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