Anterior Cruciate Ligament Reconstruction: Allograft Versus Autograft

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Purpose: This study was performed to compare the minimal 2-year outcome of anterior cruciate ligament (ACL) reconstruction using bone–patellar tendon–bone (BPTB) allografts versus autografts, both augmented with an iliotibial band tenodesis. **Type of Study:** Retrospective review. **Methods:** Forty-six of 52 BPTB ACL reconstructions using allografts and 33 of 37 BPTB ACL reconstructions using autografts were followed up at a mean of 2.75 and 3.36 years, respectively. All patients had an iliotibial band tenodesis. Evaluations included the Lysholm II scale, a questionnaire, physical examination findings, and KT-1000 arthrometry. **Results:** No statistically significant differences were seen between groups in Lysholm II scores or in any subjective category. Most patients (91% allograft; 97% autograft) had good to excellent Lysholm II scores. Sixty-five percent of allograft patients and 73% of autograft patients returned to their preinjury activity level. More allograft patients complained of retropatellar pain (16% *v* 9% for autograft patients). Fifty-three percent of allograft patients versus 23% of autograft patients had a flexion deficit of 5° or more when compared with the normal contralateral side. When comparing KT-1000 side-to-side differences, we found no significant differences between groups. Ninety-one percent of both groups had maximum side-to-side differences less than 5 mm. Three allograft patients (6.5%) had traumatic ruptures at 12, 19, and 43 months postoperatively versus none in the autograft group. All three allograft patients who sustained postoperative traumatic ruptures had received fresh frozen, nonirradiated allografts. **Conclusions:** Results of ACL reconstruction using allografts or autografts augmented with an iliotibial band tenodesis were comparable. The BPTB autograft should remain the gold standard, although the BPTB allograft in ACL reconstruction is a reasonable alternative. **Key Words:** Allograft cruciate ligament reconstruction—Allograft—Autograft.

Anterior cruciate ligament (ACL) reconstruction using an autogenous bone–patellar tendon–bone (BPTB) graft has evolved to be the gold standard. It is the most common surgical method for treating ACL-deficient knees.[1-3] Studies have shown greater fixation strength, superior mechanical properties, and good long-term results with this technique.[4-6] However, despite this success, BPTB autograft ACL replacement is also associated with complications, including quadriceps weakness, arthrofibrosis, patellofemoral pain, patellar tendinitis or rupture, patellar fracture, and patella infera syndrome.[7-11] In addition, the size of the autograft is limited to the width of the native patellar tendon and may not be appropriate to use in the presence of patella baja, multiple ligamentous injury, or revision surgery.

Good clinical results have been reported with the use of BPTB allografts for 2 to 5 years of follow-up.[1-3,12-14] However, to our knowledge, no comparative studies on the outcome of 2-incision BPTB allograft versus autograft ACL reconstructions augmented with an iliotibial band tenodesis have been published. The purpose of this study is to compare outcomes for these techniques. We hypothesize that the outcomes in

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both the allograft and autograft groups would be comparable.

METHODS

From January of 1992 to December of 1995, 324 ACL reconstructions were performed by the senior author (A.B.R.). During this period, 64 patients underwent an ACL reconstruction using allogeneic tissue. In 1994, 57 patients had undergone ACL reconstruction with an autograft BPTB. These patients were selected as a comparative group so that the numbers in each group (allograft versus autograft) would be closer, and the average time to follow-up would be nearly the same. Patients who underwent revision ACL surgery, previous patellar realignment procedures, had chronic patellar subluxation, or concomitant posterolateral corner injuries, and patients who did not have augmentation with an iliotibial band tenodesis during the index procedure were excluded. Patients with medial collateral ligament injuries, bilateral ACL reconstructions, and contralateral ACL deficits were included in the review.

After a thorough explanation of treatment options, risks, and benefits, the patients chose an ACL reconstruction with either an allogeneic or autogenous patellar tendon. Deciding factors included a smaller incision and risk of infection (HIV, hepatitis C) associated with the allografts and potential increased donor site morbidity associated with the autografts. Fifty-two patients who underwent allograft ACL reconstructions and 37 patients who underwent autograft ACL reconstructions fulfilled these criteria. These patients were further grouped into acute ($\leq$ 3 weeks from injury to surgery), subacute ($>$ 3 weeks and $<$ 6 months from injury to surgery), and chronic ($\geq$ 6 months from injury to surgery).

Preoperative and operative parameters evaluated for group equivalencies included age, gender, mechanism of injury, time between injury and surgery, concomitant injuries, arthroscopic findings, preoperative radiographic findings, preoperative examination under anesthesia, preoperative KT-1000 arthrometry, operative procedures, width of the graft, and isometry measurements. Information regarding allograft preparation (eg, fresh-frozen *v* freeze-dried, irradiated *v* non-irradiated) was noted when data were available.

Operative Procedures

A diagnostic arthroscopy was performed with partial meniscectomy, meniscal repair, removal of loose bodies, excision of plica, and chondroplasty performed if indicated. Intraoperative findings were noted, and chondromalacia was graded according to the adaptation of the Outerbridge classification by Insall et al.[15] A notchplasty was performed to adequately visualize the over-the-top position and prevent graft impingement. Approximately 2 to 4 mm of the lateral condyle was burred away. BPTB grafts were prepared either from a harvested autograft or from an allograft. Exsanguination with a tourniquet was used to harvest the autografts and for allograft cases that required improved arthroscopic visualization. All allografts had been procured, processed, and distributed to meet American Association of Tissue Bank Standards. The allograft was sized to a 10-mm sizer and measured an average of 14.3 mm wide (range, 10 mm to 16 mm). The width of the autograft was determined based on the width of the native patellar tendon. This averaged 13.0 mm wide (range, 10 mm to 15 mm) or 38% of the patellar tendon (range, 32% to 43%). The autograft was passed through a 9 or 10 mm sizer on each end.

A 3 to 5 cm longitudinal incision was made over the distal lateral femur. A strip of the iliotibial band measuring 1 to 1.5 cm was created and retracted distally. An approximately 3 cm incision was made about the medial proximal tibia. The vector drill guide was then used to drill a 9- or 10-mm drill tunnel through the proximal tibia, entering the joint space at the previous insertion of the ACL. The isotac and isometer were used to find the isometric point on the distal femur, and the excursion over a range of motion of 0° to 90° was measured. This excursion averaged 1.4 mm (0 to 4.5 mm) for allograft patients and 1.8 mm (0 to 4 mm) for autograft patients. The femoral tunnel was drilled using the vector drill guide using a two-incision technique. The tunnels were chamferred and smoothed with a Gore-Tex smoother (W.L. Gore, Elkton, MD). The grafts were internally rotated approximately 180° and fixed under tension using 2 Kurosaka cannulated interference screws (DePuy, Warsaw, IN). The reconstruction was augmented with a lateral tenodesis created using a No. 2 Mitek suture anchor (Mitek, Westwood, MA) to secure the strip of iliotibial band to the lateral femoral condyle.

Rehabilitation Protocol

During the first postoperative month, the Bledsoe brace was worn at all times, locked within a range of motion of 0° to 90°. Range of motion exercises within the brace, including straight leg raising and hamstring

curls, were begun. Full weight-bearing was encouraged as tolerated.

During the second postoperative month, patients continued to wear the Bledsoe braces; however, range of motion was increased to 0° to 135°. Patients were allowed to remove their braces at night. They started shallow squats and leg presses with moderate weight, bike riding, and stair climbing exercises. Open chain exercises were avoided.

By the third postoperative month, patients discontinued wearing the Bledsoe brace, and a patella-stabilizing brace was used in its place. The same exercises were continued with increased resistance. At the fourth postoperative month, active walking on level ground was initiated. By the fifth postoperative month, patients started running. Cutting and figure-8 exercises were incorporated at 6 months postoperatively. By 7 to 9 months, patients were allowed to return to full activities and sports in a graduated fashion.

Subjective and Objective Evaluation

Patients were contacted by letter or telephone to return for a final follow-up examination or complete a questionnaire. All patients were interviewed and evaluated by the resident physician (S.K.C. or M.D.S.) rather than by the surgeon who performed the procedures. Outcomes were evaluated using the Lysholm II scale and a devised questionnaire. Specific questions included whether or not the patient was able to return to preinjury level of activity, had retropatellar pain, was satisfied with the surgery, and would have undergone the same operation to reconstruct their ACL. They were asked to quantify their rehabilitation compliance by a percentage number (ie, fully compliant is 100%).

The physical examination included the Lachman's test (0, normal; 1+, mild; 2+, moderate; 3+, severe), pivot shift test (0, normal; 1+, glide; 2+, jump; and 3+, transient lock), range of motion, patellofemoral findings and crepitus (0, normal; 1+, mild; 2+, moderate; 3+, severe), muscle atrophy (circumferential measurements compared with the contralateral limb at the joint line, 5 cm proximal to the superior pole of the patella, and 15 cm proximal to the superior pole of the patella), and the presence of an effusion (0, normal; 1+, mild; 2+, moderate; 3+, severe).

A KT-1000 arthrometric evaluation was obtained at follow-up. Patients were placed supine and anterior translation was measured with the knee flexed at 30° using 15 lb (67 N), 20 lb (89 N), and maximum manual force. Posterior translation was measured at 15 lb and 20 lb. Side-to-side evaluations were performed. Patients with contralateral ACL deficiencies and those who had bilateral ACL reconstructions were excluded from side-to-side comparisons of range of motion, thigh circumference 5 cm proximal to the superior pole of the patella, and arthrometric measurements.

Statistical data were analyzed using version 3.2.1 of JMP Software (SAS Institute, Cary, NC). Categorical data were analyzed by χ-square analysis or Fisher Exact test. Analysis of variance (ANOVA) tested equivalencies in continuous data. Statistical significance was set at $P \leq .05$.

RESULTS

Preoperative and intraoperative data were available on all 46 allograft patients and 33 autograft patients. Data on the allograft preparation were available in only 40 of the cases; all were fresh-frozen, with 30 nonirradiated and 10 irradiated. Data on the amount of radiation used were not available. The groups were statistically equivalent for most variables except for a few important differences. The allograft group was older, averaging 33.1 years versus the autograft group, which averaged 28.7 years of age. There were significantly more men in the allograft group at 41 of 46 (89.1%) versus 19 of 33 (57.6%) in the autograft group. The autograft group had more medial collateral ligament injuries at 6 of 33 (18.2%) versus 1 of 46 (2.1%) in the allograft group. KT-1000 testing showed greater preoperative laxity in the allograft group, with maximum manual differences of 6.9 mm versus 4.8 mm in the autograft group. There was also a higher rate of chondromalacia of the medial tibial plateau in the allograft group versus the autograft group (5 of 46 [10.9%] versus 0 of 33 [0%]). Finally, on average, the width of the graft obtained was wider for allograft patients at 14.3 mm versus 13.0 mm (Tables 1-3).

Subjective Results

Forty-six of 52 (88%) BPTB allograft ACL reconstructions and 33 of 37 (89%) BPTB autograft ACL reconstructions were evaluated by a final questionnaire including the Lysholm II scale, with an average follow-up of 33 months (24 to 56 months) and 40 months (33 to 47 months), respectively ($P < .0001$). One patient underwent bilateral ACL reconstructions using allografts; data from both procedures were included in the analysis. Three allograft patients experienced traumatic ruptures at 12, 19, and 43 months

Table 1. *Preoperative and Intraoperative Comparison of Groups: Variables With Significant Differences*

Parameter	Allograft Group	Autograft Group	*P* Value
Total number	46	33	
Time to follow-up	2.8 ± 0.8 (2-4.7) yr	3.4 ± 0.1 (2.8-3.9) yr	<.0001
Age	33.1 ± 9.5 (16-52) yr	28.7 ± 9.7 (13-51) yr	.05
Sex	41/46 (89.1%) males	19/33 (57.6%) males	.001
Width of graft	14.3 ± 1.0 (10-16) mm	13.0 ± 1.5 (10-15) mm	<.0001
Medial collateral ligament injuries	1/46 (2.1%)	6/33 (18.2%)	.014
KT-1000 maximum-manual difference	6.9 ± 4.2 (0-20) mm	4.8 ± 3.7 (−3.5-14) mm	.02

postoperatively, versus no patients in the autograft group ($P = .1$). All of the ruptures occurred while the patients were participating in the same sporting activity that caused the initial ACL rupture, with similar mechanisms of injury. The three allograft patients with postoperative traumatic ruptures all had fresh-frozen, nonirradiated allografts. All 3 patients had returned to full activity, had no subjective complaints, and were completely satisfied with their surgery before their postoperative ruptures. Based on the observed postoperative rupture rates, 116 cases in each group would have been required to have had an 80% chance of obtaining a statistically significant difference (power analysis).

The 3 allograft procedures with postoperative traumatic ruptures were considered treatment failures. The remaining 43 allograft patients averaged 93.8 points, whereas the autograft patients (n = 33) scored a mean of 95.5 points in Lysholm II scores. Thirty-nine of 43 (91%) allograft patients compared with 32 of 33 (97%) autograft patients had good to excellent Lysholm II scores (≥84 points). Three allograft patients versus one autograft patient had a fair rating (65 to 83 points), and only one allograft patient had a poor rating (≤64 points). No significant differences were seen between groups for each Lysholm II score subcategory. Seven of 43 allograft patients (16%) versus 2 of 33 autograft patients (6%) had subjective instability rarely during athletics or other severe exertion.

Twenty-eight of 43 (65%) allograft patients versus 24 of 33 (73%) autograft patients were able to return to preinjury activity levels. Reduction in activity was related to knee problems in the affected knee in 9 of 15 (60%) allograft patients and 3 of 9 (33%) autograft patients. Retropatellar pain was present in 7 of 43 (16%) allograft patients and 3 of 33 (9%) autograft patients. However, this difference was not statistically significant. Interestingly, none of the patients with postoperative retropatellar pain had chondromalacia noted at the time of surgery. Moreover, none of the patients with chondromalacia at the time of surgery had retropatellar pain at final follow-up. The autograft patients were more adherent to rehabilitation, rating themselves at an average of 98% compliance. The allograft patients rated themselves at an average of 92% compliance ($P = .06$). Allograft patients were less satisfied with their surgery than autograft patients at 93% (40 of 43) versus 100% satisfaction ($P = .1$). Forty-one of 43 (95%) allograft versus 32 of 33 (97%) autograft patients would retrospectively have undergone the same operation with the same surgeon (Table 4).

Objective Results

Excluding the 3 allograft patients with postoperative traumatic ruptures, 38 of 43 (88.4%) allograft patients and 28 of 33 (84.8%) autograft patients returned to the clinic for a final examination. Two allograft patients and 3 autograft patients had contralateral ACL deficiencies. Two allograft reconstructions and 3 autograft reconstructions were associated with contralateral ACL reconstructed knees. This left 34 allograft patients and 22 autograft patients available for side-to-side comparisons of range of motion, thigh circumference 5 cm proximal to the superior pole of the patella, and arthrometric measurements.

Twelve of 38 (32%) allograft patients had a positive Lachman's test versus 5 of 28 (18%) of autograft patients ($P = .2$). All positive Lachman's test results were grade 1 and had firm endpoints. Two of the 38 allograft patients had grade 1 pivot shift tests versus none of the autograft patients ($P = .2$). There were no significant differences in anterior translation at 15 lb, 20 lb, and maximum manual force on arthrometric testing between groups. There were no statistically significant differences in patellofemoral crepitus between groups. Four of the 38 (11%) allograft patients versus 1 of 28 (4%) autograft patients had postoperative arthrofibrosis. No patients in either group

TABLE 2. *Preoperative and Intraoperative Comparison of Groups: Variables Without Significant Differences*

Parameter	Allograft Group (n = 46)	Autograft Group (n = 33)	*P* Value
Knee side (right/left)	17/29	14/19	.6
Contralateral deficient ACL	2/46 (4.4%)	3/33 (9.1%)	.4
Previous contralateral ACL reconstruction	2/46 (4.4%)	3/33 (9.1%)	.4
Mean time from injury to surgery	18.3 ± 28 (0.4-118) mo	25.1 ± 43.8 (0.5-196) mo	.4
Acute injuries (≤3 wks from injury to surgery)	3/46 (6.5%)	3/33 (9.1%)	.5
Subacute injuries (>3 wks and <6 mo from injury to surgery)	23/46 (50%)	12/33 (36.4%)	.5
Chronic injuries (≥6 mo from injury to surgery)	20/46 (43.5%)	18/33 (54.6%)	.5
Previous medial meniscectomy	6/46 (13%)	4/33 (12%)	.9
Previous lateral meniscectomy	0/46 (0%)	2/33 (6%)	.09
Previous medial meniscal repairs	0/46 (0%)	1/33 (3%)	.2
Mechanism of injury			
Sports-related injury	42/46 (91.3%)	29/33 (87.9%)	.6
Basketball	15/46 (32.6%)	10/33 (30.3%)	.8
Skiing	8/46 (17.4%)	6/30 (18.2%)	.8
Football	5/46 (10.9%)	5/33 (15.2%)	.8
Volleyball	6/46 (13%)	3/33 (9.1%)	.8
Soccer	3/46 (6.5%)	3/33 (9.1%)	.8
Work-related injury	1/46 (2.2%)	3/33 (9.1%)	.8
Fall	2/46 (4.4%)	0	.8
Motor vehicle accident	1/46 (2.2%)	1/33 (3%)	.8
Softball	1/46 (2.2%)	1/33 (3%)	.8
Running	1/46 (2.2%)	0	.8
Skateboarding	1/46 (2.2%)	0	.8
Tae kwon do	0	1/33 (3%)	.8
Tennis	1/46 (2.2%)	0	.8
Wrestling	1/46 (2.2%)	0	.8
Medial meniscal tear	17/46 (37%)	7/33 (21%)	.13
Partial medial meniscectomy	13/46 (28.3%)	4/33 (12.1%)	.09
Medial meniscal repair	2/46 (4.4%)	3/33 (9.1%)	.4
Lateral meniscal tear	23/46 (50%)	13/33 (39.4%)	.35
Partial lateral meniscectomy	14/46 (30.4%)	7/33 (21.2%)	.36
Lateral meniscal repair	3/46 (6.5%)	3/33 (9.1%)	.7
Removal of loose bodies	1/46 (2.2%)	1/33 (3%)	.8
Excision of plica	1/46 (2.2%)	2/33 (6%)	.4
Chondroplasty medial femoral condyle	1/46 (2.2%)	0	.4
Chondroplasty lateral femoral condyle	1/46 (2.2%)	0	.4
KT-1000 Translation with maximum-manual force	16.7 ± 4.9 (10-30) mm	16.2 ± 3.7 (9-24) mm	.7
KT-1000 Maximum-manual difference ≥3 mm	39/46 (84.8%)	25/33 (75.8%)	.3
Positive Lachman under anesthesia	45/46 (97.8%)	32/33 (97%)	.8
Grade 1	9/46 (19.6%)	4/33 (12.1%)	.8
Grade 2	29/46 (63%)	21/33 (63.6%)	.8
Grade 3	7/46 (15.2%)	7/33 (21.2%)	.8
Positive pivot shift under anesthesia	44/46 (95.7%)	31/33 (93.9%)	.7
Grade 1	6/46 (13%)	3/33 (9.1%)	.9
Grade 2	29/46 (63%)	20/33 (60.6%)	.9
Grade 3	9/46 (19.6%)	8/33 (24.2%)	.9
Intraoperative isometry measured	1.4 ± 1.0 (0-4.5) mm	1.8 ± 1.1 (0-4) mm	.1

showed an effusion at latest follow-up. Two allograft patients underwent one additional operation each. The first patient underwent arthroscopy for debridement, removal of loose bodies, and chondroplasty. The second underwent manipulation under anesthesia for arthrofibrosis (Table 5).

Two allograft patients had extension deficits of 5°, and one had a deficit of 10°. The autograft patients had no extension deficits. The average flexion deficit was 4.7° for allograft patients and 1.8° for autograft patients ($P = .07$). Eighteen of 34 (53%) allograft patients versus 5 of 22 (22.7%) autograft patients had a

Table 3. *Comparison of Chondromalacia by Groups*

Parameter	Allograft Group	Autograft Group	*P* Value
Chondromalacia present	18/46 (39.1%)	10/33 (30.3%)	.4
Chondromalacia patella	7/46 (15.2%)	4/33 (12.1%)	.7
Grade 1	4/46 (8.7%)	0	.3
Grade 2	2/46 (4.4%)	3/33 (9.1%)	.3
Grade 3	1/46 (2.2%)	1/33 (3%)	.3
Chondromalacia medial femoral condyle	5/46 (10.9%)	2/33 (6%)	.5
Grade 1	0	1/33 (3%)	.3
Grade 2	2/46 (4.4%)	0	.3
Grade 3	3/46 (6.5%)	1/33 (3%)	.3
Chondromalacia lateral femoral condyle	3/46 (6.5%)	0	.13
Grade 4	3/46 (6.5%)	0	.13
Chondromalacia medial tibial plateau	5/46 (10.9%)	0	.05*
Grade 1	1/46 (2.2%)	0	.4
Grade 2	2/46 (4.4%)	0	.4
Grade 3	1/46 (2.2%)	0	.4
Grade 4	1/46 (2.2%)	0	.4
Chondromalacia lateral tibial plateau	2/46 (4.4%)	3/33 (9.1%)	.4
Grade 1	1/46 (2.2%)	1/33 (3%)	.5
Grade 2	0	1/33 (3%)	.5
Grade 3	1/46 (2.2%)	0	.5
Grade 4	0	1/33 (3%)	.5
Chondromalacia trochlea	5/46 (10.9%)	2/33 (6%)	.5
Grade 1	1/46 (2.2%)	2/33 (6%)	.3
Grade 2	3/46 (6.5%)	0	.3
Grade 3	1/46 (2.2%)	0	.3

*Statistically significant.

Table 4. *Comparison of Subjective Results Between Groups Excluding Postoperative Traumatic Ruptures*

Parameter	Allograft Group	Autograft Group	*P* Value
No. of patients available for evaluation	43	33	
Lysholm II scale total score	93.8 ± 7.3 (63-100)	95.5 ± 5.2 (80-100)	.25
Limp	4.5 ± 0.9 (3-5)	4.8 ± 0.7 (3-5)	.15
Support	5	5	
Locking	14.6 ± 2.1 (2-15)	14.8 ± 0.9 (10-15)	.5
Instability	24.2 ± 1.9 (20-25)	24.7 ± 1.2 (20-25)	.2
Pain	22.0 ± 2.9 (15-25)	22.4 ± 3.6 (10-25)	.5
Swelling	9.2 ± 1.6 (6-10)	9.2 ± 1.6 (6-10)	.0
Stair climbing	9.7 ± 1.0 (6-10)	9.9 ± 0.7 (6-10)	.5
Squatting	4.7 ± 0.5 (4-5)	4.8 ± 0.4 (4-5)	.4
Complaints of instability	7/43 (16.3%)	2/33 (6%)	.2
Lysholm scores excellent (95-100)	24/43 (55.8%)	23/33 (69.7%)	.5
Lysholm scores good (84-94)	15/43 (34.9%)	9/33 (27.3%)	.5
Lysholm scores fair (65-83)	3/43 (7%)	1/33 (3%)	.5
Lysholm scores poor (≤64)	1/43 (2.3%)	0	.5
Unable to return to preinjury activity level	15/43 (34.9%)	9/33 (27.3%)	.5
Knee-related reduction in activity	9/43 (20.9%)	3/33 (9.1%)	.2
Rehabilitation compliance	92.4 ± 16.3% (20-100)	98.2 ± 6.2% (70-100)	.06
Retropatellar pain	7/43 (16.3%)	3/33 (9.1%)	.4
Satisfied with surgical outcome	40/43 (93%)	33/33 (100%)	.12
Would do the same surgical procedure	41/43 (95.4%)	32/33 (97%)	.7

TABLE 5. *Comparison of Objective Results Excluding Postoperative Traumatic Ruptures and Comparative Side-to-Side Analysis*

Parameter	Allograft Group	Autograft Group	*P* Value
No. of patients available for analysis	38	28	
KT-1000 anterior translation at 15 lb of force	4.6 ± 2.1 (0.5-11) mm	4.1 ± 1.8 (1.5-8) mm	.4
KT-1000 anterior translation at 20 lb of force	6.1 ± 2.5 (1.5-13) mm	5.7 ± 2.0 (3-10.5) mm	.4
Compliance index determination (CID)	1.6 ± 0.8 mm	1.6 ± 0.6 mm	.9
Patients with a CID >2	13/38 (34.2%)	9/28 (32.1%)	.9
KT-1000 anterior translation at maximum-manual force	8.4 ± 3.1 (2-16) mm	8.3 ± 2.6 (5-14) mm	.8
Patients with an anterior translation >10 mm at maximum-manual force	13/38 (34.2%)	5/28 (17.9%)	.14
Postop anterior translation at maximum-manual force minus preop anterior translation at maximum-manual force	−8.0 ± 4.9 mm	−8.3 ± 3.3 mm	.8
Grade 1 Lachman test with firm endpoint	12/38 (31.6%)	5/28 (17.9%)	.2
Grade 1 pivot shift tests	2/38 (5.3%)	0	.2
Positive patellofemoral crepitus	21/38 (55.3%)	17/28 (60.7%)	.7
Grade 1 patellofemoral crepitus	20/38 (52.6%)	17/28 (60.7%)	.6
Grade 2 patellofemoral crepitus	1/38 (2.6%)	0	.6
Postop Lachman test–Pre-op Lachman Test	−1.7 ± 0.8	−1.8 ± 0.9	.4
Postop pivot-shift test–Preop pivot-shift test	−2.0 ± 0.7	−2.0 ± 0.8	.7
Total knee range of motion	137.6° ± 10.8° (100°-165°)	141.1° ± 8.8° (115°-155°)	.2
Arthrofibrosis (flexion contracture ≥5°)	4/38 (10.5%)	1/28 (3.6%)	.3

flexion deficit of 5° or more ($P = .02$). The allograft group had 8 patients with flexion deficits of 5°, 7 had deficits of 10°, 2 had deficits of 15°, and one had a deficit of 20°. The autograft group had one flexion deficit of 5°, 2 with deficits of 10°, and 2 with deficits of 15°. Twenty-five of 34 (74%) allograft patients versus 20 of 22 (90.9%) autograft patients had either a range of motion equal to or better than the normal contralateral normal knee, or a range of motion of at least 0° to 135° ($P = .1$) (Table 6).

There were no significant differences in vastus medialis obliquus atrophy between groups. In addition, no statistically significant differences were seen between groups in side-to-side arthrometric differences at 15 lb, 20 lb, and maximum manual force. Thirty-one of 34 (91%) allograft patients and 20 of 22 (91%)

TABLE 6. *Comparison of Objective Results Excluding Patients With Postoperative Traumatic Ruptures, Contralateral ACL Deficiencies, and Contralateral ACL Reconstructions*

Parameter	Allograft Group	Autograft Group	*P* Value
Patients available for side-to-side analysis	34	22	
KT-1000 maximum-manual difference	1.2 ± 2.5 (−4-9) mm	1.1 ± 2.6 (−3-8) mm	.9
Patients with maximum-manual difference <3 mm	28/34 (82.4%)	19/22 (86.4%)	.7
Patients with maximum-manual difference <5 mm	31/34 (91.2%)	20/22 (90.9%)	1.0
Patients with both a maximum-manual difference ≥3 mm and anterior translation at maximum force >10 mm	3/34 (8.8%)	3/22 (13.6%)	.6
Normal range of motion achieved (0°–135° or equivalent to contralateral side)	25/34 (73.5%)	20/22 (90.9%)	.1
Mean loss of extension	0.6° ± 2.0° (0°-10°)	0	.2
Patients with a flexion contracture ≥5°	3/34 (8.8%)	0	.15
Mean loss of flexion	4.7° ± 5.5° (0°-20°)	1.8° ± 5.9° (−10°-15°)	.07
Patients with ≥5° of flexion loss	18/34 (53%)	5/22 (22.7%)	.02*
VMO circumference operated side–VMO circumference contralateral side (5 cm proximal to superior pole of the patella)	−0.3 ± 1.3 (−2.5-3) cm	−0.4 ± 1.2 (−2.5-2) cm	.7
Patients with VMO atrophy	20/34 (58.8%)	10/22 (45.5%)	.3

*Statistically significant.

autograft patients had maximum manual side-to-side differences less than 5 mm.

DISCUSSION

Despite tremendous success with the use of autogenous BPTB grafts, we continue to look for reasonable alternatives in an attempt to limit its complications. Theoretically, the use of a BPTB allograft could equal the bony fixation associated with BPTB autografts and limit extensor mechanism complications. The literature suggests that the BPTB allograft may be a reasonable alternative to the BPTB autograft. However, concerns about disease transmission, delayed graft incorporation, potential immune reactions, a decreased maximum load, sterilization and graft preparation problems, bone tunnel enlargement, increased postoperative traumatic rupture rate, graft cost, long-term results, and a paucity of comparison studies have tempered our enthusiasm about the use of BPTB allograft ACL reconstruction.[1-3,13,14,16-18]

Promising results from animal studies using allogeneic tissue have encouraged its use in humans.[19,20] In their study using deep-frozen bone–ACL–bone allografts in a dog model, Goertzen et al.[19] showed that the highest tensile strength of the allografts was up to 69.1% of the contralateral ACL at 12 months, which is equivalent to the tensile strength of the semitendinosus tendon. However, in a goat model using patellar tendon allografts, Jackson et al.[20] found that the allografts showed a greater decrease in the implantation structural properties, a slower rate of biologic incorporation, and the prolonged presence of an inflammatory response. Moreover, at 6 months, the autograft showed a more robust biologic response, improved stability, and increased strength to failure compared with the allograft.[20] Kirkpatrick et al.[21] noted a delay in revascularization and cellular repopulation in allografts compared with autografts in a dog model. Maximum load was also smaller in the allografts than in autografts. Several studies showed little immune response with deep-frozen or freeze-dried allografts.[19,22,23] Conversely, Vasseur et al.[24] and Thorson et al.[25] showed evidence of inflammatory responses in dogs to frozen bone–ligament–bone allografts and recommended against the use of allografts because of these poor results.

A number of comparative studies have indicated that the results from BPTB allografts versus BPTB autografts are similar.[2,3,13,14] However, Stringham et al.[3] were concerned about an increased postoperative traumatic rupture rate with allografts, and Victor et al.[18] recommended against allografts because they concluded that stability deteriorated over time. In a recent study by Malinin et al.[26] of 9 retrieved allograft specimens and 1 autograft specimen from autopsy and surgery, it was determined that the allograft becomes revascularized and replaced with host cells. However, at 2 years after transplantation, the central portions of the grafts remained avascular and complete attachment was not present.[26]

Concern about disease transmission has primarily centered around HIV and hepatitis C. The estimated risk of HIV transmission is 1 in 1,600,000.[27] Recently, 4 cases of septic arthritis after ACL reconstruction with contaminated bone–tendon–bone allografts were reported.[28]

We selected augmentation with an iliotibial band tenodesis based on the initial recommendation of Noyes et al.[29] for its use in patients with chronic ACL deficiencies treated with BPTB allograft reconstructions. The extra-articular procedure appeared to provide support to the healing intra-articular allograft by reducing deleterious forces and tibial displacements, and to restore the secondary restraints provided by the iliotibial band. Interestingly, Noyes et al.[30] performed a subsequent study and found that the extra-articular procedure did not yield any appreciable benefit with regard to reducing anteroposterior displacement. Subsequently, Noyes et al. no longer perform the extra-articular procedure with their allograft ACL reconstructions.[30] We believe that the discrepancy in anterior translation and complaints of instability were higher than the comparatively low numbers of pivot shifts on follow-up secondary to the effect of the iliotibial band tenodesis. The iliotibial band tenodesis theoretically eliminates the pivot shift phenomena by preventing the anterior translating effect of the iliotibial band in extension.

In our study, we used fresh-frozen BPTB allografts, the majority of which were nonirradiated. Previous studies suggested that radiation weakened allografts.[31-33] No evidence was seen of rejection or symptomatology suggestive of an inflammatory response caused by the allograft. Moreover, all postoperative traumatic allograft ruptures were nonirradiated.

Subjectively, the allograft patients did nearly as well as the autograft patients. The mean Lysholm II scores were almost identical, although a higher percentage of autograft patients had excellent scores (70% *v* 56%). Moreover, no statistically significant differences were seen in any subjective category. The autograft group was more adherent with rehabilitation

and had higher rates of satisfaction with the surgery. However, these differences were not statistically significant.

No statistically significant differences were seen in patellofemoral crepitus between groups. More allograft patients had retropatellar pain (16%) than autograft patients (9%). However, these differences were also not statistically significant. Our results are comparable to those from a study by Stringham et al.,[3] who reported retropatellar pain in 13% of their allograft patients and 9% of their autograft patients. Interestingly, chondromalacia noted intraoperatively was not associated with postoperative retropatellar pain. The differences in postoperative range of motion and patellofemoral symptoms and signs did not appear to be related to harvesting the central third of the patellar tendon.

Objectively, the only parameter with a statistically significant difference was that more allograft patients had flexion deficits (53% *v* 23%). The allograft group was older, predominantly men, and less adherent to rehabilitation programs. Perhaps this played a role in this difference. No significant differences were seen in side-to-side arthrometric analysis. Our results for both groups of a rate of 91% maximum manual side-to-side differences of less than 5 mm were comparable to those from a study by Harner et al.[1] They reported that 94% of allograft patients and 92% of autograft patients achieved this result. The allograft group showed a higher percentage of grade 1 Lachman's tests (32% *v* 18%) and a larger number of patients with anterior translation greater than 10 mm (34% *v* 18%) on arthrometric testing. However, all positive Lachman's tests had firm endpoints, and differences between groups were not statistically significant.

The 3 postoperative traumatic ruptures in the allograft group are cause for concern. Although the differences were not statistically significant, analysis showed that we did not achieve adequate power. Animal studies suggest that the ultimate strength of the allograft is inferior to the autograft.[20,21,25] This may predispose allograft patients to traumatic ruptures at less deforming forces than autograft patients. Conversely, using an allograft theoretically allows the surgeon to select a wider and perhaps biomechanically stronger graft at the time of surgery. Our allografts were, on average, significantly wider than autografts (14.3 *v* 13.0 mm). Rates of postoperative traumatic ruptures in patients with allograft ACL reconstructions range from 7% to 13%.[3,18,34] In comparison, BPTB autograft ACL reconstructions have reported postoperative traumatic rupture rates from 0% to 5%.[5,6,34,35] The 3 postoperative traumatic allograft failures in our series all occurred during activities similar to those in which the ACL was injured initially. If we define our failures as any patient with a maximum manual difference greater than or equal to 5 mm and include our posttraumatic ruptures, then our failure rate was 6 of 37 (16.2%) for allograft patients and 2 of 22 (9.1%) for autograft patients.

Limitations of the study include that this was a retrospective study with small numbers and a short follow-up period. The comparison groups were not identical because the allograft group had significantly more men and was older. Because we included patients with bilateral ACL reconstructions and contralateral ACL deficiencies, this limited the number of side-to-side comparisons that could be made.

In summary, the results of our allograft BPTB ACL reconstructions were comparable but not as good as the results of our autograft BPTB ACL reconstructions. For this reason, we believe that autograft BPTB reconstructions should remain the gold standard. However, based on our acceptable allograft results, which were nearly equivalent to those for autograft BPTB ACL reconstructions, allograft BPTB reconstruction augmented with an iliotibial band tenodesis remains a reasonable alternative.

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