

Primary Anterior Cruciate Ligament Reconstruction Using Fresh-Frozen, Nonirradiated Patellar Tendon Allograft

Minimum 2-Year Follow-up

Bernard R. Bach, Jr,* MD, Kirk J. Aadalén, MD, Michael G. Dennis, MD, Dominic S. Carreira, MD, John Bojchuk, MS, ATCL, Jennifer K. Hayden, MSN, RN, and Charles A. Bush-Joseph, MD

From the Section of Sports Medicine, Department of Orthopedic Surgery, Rush University Medical Center, Chicago, Illinois

Background: There are conflicting reports of allograft performance, immune response, tissue incorporation, and rerupture rates when used for anterior cruciate ligament reconstruction.

Purpose: To evaluate the clinical outcome of a fresh-frozen, nonirradiated, patellar tendon allograft for primary anterior cruciate ligament reconstruction surgery.

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

Methods: Patients who underwent endoscopic primary anterior cruciate ligament reconstruction with allograft tissue a minimum of 2 years ago were evaluated with physical examinations, the KT-1000 arthrometer, functional testing, radiographic evaluation, subjective assessment, and outcomes tools.

Results: Fifty-nine patients (60 knees) were evaluated at an average of 51 months after surgery. Ninety-four percent of patients were mostly or completely satisfied. A negative pivot shift test result was noted in 90% of subjects. The KT-1000 arthrometer side-to-side differences were ≤ 3 mm in 95% of patients, and no patient exceeded 5 mm. The mean International Knee Documentation Committee score was 78 (SD = 19), and the mean Lysholm score was 82 (SD = 17). There were no clinical symptoms consistent with graft rejection or infection. Radiographic evaluation demonstrated infrequent significant tunnel widening.

Conclusions: Use of a fresh-frozen, nonirradiated allograft for primary reconstruction of the anterior cruciate ligament is a successful procedure both subjectively and functionally for restoring stability in patients selected for allograft reconstruction. In the patients selected for this surgical procedure, clinical, arthrometric stability testing, and subjective satisfaction were comparable to our previously published cohort studies using patellar tendon autograft at similar postoperative follow-up.

Keywords: anterior cruciate ligament (ACL); allograft; outcomes; arthroscopy

Data extracted and analyzed by the American Academy of Orthopaedic Surgeons Department of Research and Scientific Affairs reported that in 1995 and 1996 more than 100 000 ACL reconstructions were performed (sources: National Center for Health Statistics; *Inpatient*

*Address correspondence to Bernard R. Bach, Jr, MD, 1725 W. Harrison, Suite 1063, Chicago, IL 60612 (e-mail: brbachmd@comcast.net).

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Procedures: National Hospital Discharge Survey, 1994-2001; Outpatient Procedures: National Survey of Ambulatory Surgery, 1994-1996). Autograft tissue has traditionally been the graft of choice among most knee ligament surgeons. Because of graft site morbidity, more difficult rehabilitation, lack of suitable autograft, multiligament reconstructions, and revision situations, allograft tissue has been explored as an alternative by some surgeons.^{1,20,27,31,41,42}

In the senior author's personal practice (B.R.B.), an increased use of allografts has evolved, particularly in the past 5 years. Between 1986 and 1996, primary allograft reconstructions were performed in 2% of our patients; between 1996 and 2001, this increased to 14% and for the

past 2.5 years allograft procedures have constituted 36% of our primary ACL reconstructions. Nonirradiated patellar tendon allografts have been used exclusively since 1986 because we had concerns about irradiation affecting the material properties of the tissue. It has been the senior author's observation that the clinical stability, KT-1000 arthrometer testing, and patient satisfaction levels in the patient cohort selected for allograft reconstruction appeared comparable to autograft cohorts. The purpose of this study was to evaluate the use of a fresh-frozen, nonirradiated, bone-patellar tendon-bone allograft for primary ACL reconstruction.

MATERIALS AND METHODS

Much of the methodology used for this study is identical to the methods reported in several previous studies from this institution.⁶⁻⁸ All patients who underwent primary allograft ACL reconstruction with nonirradiated patellar tendon allograft between July 1986 and November 2000 were identified from our computerized surgical database. This outcomes study was previously approved by the Human Subjects Committee of the Institutional Review Board at Rush University Medical Center in Chicago, Illinois. Allograft options were discussed or recommended by the treating surgeons (B.R.B./C.B.J.) to patients who (1) were older than 40 years of age, (2) had radiographic evidence of mild degenerative joint disease, (3) had moderate patellofemoral crepitation or pain symptoms, (4) were of petite stature, (5) had graft donor tissue of questionable quality, or (6) requested allograft reconstruction. Exclusionary criteria included extra-articular reconstructions, high tibial osteotomy, and associated multiligamentous instability. All surgical procedures were performed by the 2 senior surgeons (B.R.B. and C.B.J.). Eighty-nine patients with ACL-deficient knees met our inclusion criteria and underwent primary reconstruction using fresh-frozen, nonirradiated patellar tendon allografts. Seven underwent bilateral reconstructions, for a total of 96 knees. A detailed questionnaire was filled out by each patient to eliminate interviewer bias. The evaluation consisted of physical examination, KT-1000 arthrometer (MEDmetric Corp, San Diego, Calif) measurements, radiographs, functional testing, and knee scoring scales. The knee scoring scales used included the Knee Injury and Osteoarthritis Outcomes Score (KOOS),⁴⁰ International Knee Documentation Committee (IKDC),³ Noyes Sports Activity Scale,³³ Tegner,⁴⁷ Lysholm,²⁹ and SF-12.⁵⁰

Surgical Technique

All patients underwent an examination under anesthesia and arthroscopy before ACL reconstruction. All patients demonstrated a positive pivot shift test result when examined under anesthesia. All other related procedures were performed before the reconstruction. Reconstruction was performed with an arthroscopic technique.⁷ Use of a single-incision technique began in October 1991; all prior patients had a dual-incision, arthroscopically assisted

reconstruction. Three patients had a dual-incision technique; 56 patients (57 knees) underwent a single-incision technique. Fresh-frozen, nonirradiated allografts were obtained from the same tissue bank (Allosource Tissue Bank, Denver, Colo). A 10-mm, middle third patellar tendon allograft was fashioned with 25-mm bone plugs. Tibial and femoral tunnels were drilled and reamed using commercially available aiming devices (Acufex Protrac Aimer, Smith & Nephew, Andover, Mass). Femoral and tibial bone plugs were secured using metal interference screw fixation. The screw length was determined intraoperatively, with the vast majority being 7 × 25-mm metal cannulated screws on the femoral side and 9 × 20-mm metal screws on the tibial side. In 4 patients, alternate fixation was used on the tibial side (staples or a screw and post) because of graft-tunnel mismatch. Alternatively, a 540° rotation of the graft to shorten the graft was used in 4 additional patients because of graft-tunnel mismatch.⁴⁸

Physical Examination

Follow-up physical examinations were performed by a sports medicine fellow (K.J.A. or M.G.D.) to reduce surgeon bias. The evaluation included supine goniometric range of motion measurements, prone heel height differences measured to the nearest centimeter, and thigh circumference measurements (8 cm proximal to the patella). Varus-valgus stability at 0° and 30°, Lachman, anterior and posterior drawer, and pivot shift tests were performed. Ligamentous laxity was graded as 1+ (0-5 mm), 2+ (5-10 mm), or 3+ (>10 mm). The pivot shift phenomenon was graded as 1+ (slip), 2+ (jump), or 3+ (transient lock) in the position of thigh abduction and external rotation, which maximizes the pivot shift phenomenon.⁹ A failure was defined as a pivot shift of any grade.

Functional Testing

Fifty-two patients (53 knees) underwent bilateral knee functional testing at the follow-up examination by an experienced athletic trainer (J.B.). This trainer also conducted the functional examinations on several previous clinical studies.⁶⁻⁸ Seven patients were unable to complete this testing predominately because of non-knee-related problems. The functional indices recorded included a timed single-legged 6-m hop, measured single-legged hop, and single-legged vertical jump. All patients underwent 3 trials of each test for each leg; the trials were averaged and reported as side-to-side differences.

Radiographs

Standing bilateral AP, standing bilateral 45° PA, lateral, and Merchant view radiographs were obtained on 54 patients (92%) at follow-up and compared to normal radiographs. Because many patients were referred to our care, preoperative radiographs were not consistently available at follow-up to compare for any evolving changes. Radiographs were graded based on the IKDC 2000 exami-

nation instructions. A mild grade indicated minimal change (small osteophytes, slight sclerosis or flattening of the femoral condyle, and narrowing of the joint space is just detected). A moderate grade had these changes and joint space narrowing (a joint space of 2-4 mm or 50% joint space narrowing). Severe changes included a joint space <2 mm or >50% joint space narrowing. The radiographs were interpreted by a sports medicine fellow (K.J.A.) and subsequently reviewed by 1 of the senior authors (B.R.B.).

Arthrometric Examination

The KT-1000 arthrometer (MEDmetric Corp) was used by an experienced independent examiner (J.B.) to obtain preoperative and postoperative translation measurements. Testing was performed as described by Daniel et al.¹⁴ Anterior maximum manual and maximum manual side-to-side differences were calculated. An arthrometric failure was defined as a side-to-side difference of 5 mm. Results were stratified into ≤ 3 mm, 3.1 to 4.9 mm, and ≥ 5 mm.

Questionnaire

A detailed questionnaire was developed that included the 2000 IKDC Subjective Knee Evaluation Form,³ KOOS,⁴⁰ Noyes Sports Activity Scale,³³ Tegner,⁴⁷ Lysholm,²⁹ and SF-12.⁵⁰ The questionnaire also included a visual analog scale for pain ratings. The questionnaire was completed by the patient to eliminate interviewer bias. Subjective patient satisfaction was stratified by patients rating their satisfaction level as *completely*, *mostly*, *somewhat*, or *dissatisfied*.

Rehabilitation

All patients were enrolled in an accelerated postoperative rehabilitation protocol that included gait training, straight leg raises, prone heel hangs, and range of motion exercises. All knees were immobilized in a drop-lock knee brace locked in full extension for ambulation for 2 weeks after surgery. Patients were allowed to unlock or remove the brace for range of motion exercises, and the brace was discontinued once patients were comfortable, had at least 90° of flexion, and demonstrated good quadriceps control. Weightbearing as tolerated and unrestricted range of motion was allowed immediately after surgery. Patient comfort was used as the criteria for discontinuation of crutches, which usually occurred by 1 week after surgery. A formal supervised rehabilitation program was prescribed using a standard protocol so that patients could have their postoperative rehabilitation at outside facilities. This formal rehabilitation program was initiated within the first postoperative week. Bicycling was allowed by 2 weeks, use of stair-climbing machines was permitted at 4 to 6 weeks, straight-ahead jogging was allowed at 12 to 16 weeks, and gradual return to sports was allowed between 4 to 6 months after surgery if rehabilitation goals were met. This rehabilitation program was identical to our

primary patellar tendon autograft protocol except for the reduced time in the drop-lock brace. A custom ACL orthosis was worn from 6 weeks to 6 months after surgery for activities of daily living and was used for sports from 6 months to 1 year after surgery, which was the identical protocol used for our autografts reconstructions at that time period.

Data Acquisition and Analysis

All data were recorded on scannable Teleform (Cardiff Software, Inc, San Diego, Calif) sheets so that data could be automatically input into a computer database. Descriptive statistics, analysis of variance testing, χ^2 analysis, Friedman tests, and Pearson correlation coefficients were employed where applicable. Statistical analysis was performed using the SPSS version 10 software package (SPSS Inc, Chicago, Ill). Statistical significance was established at $P = .05$.

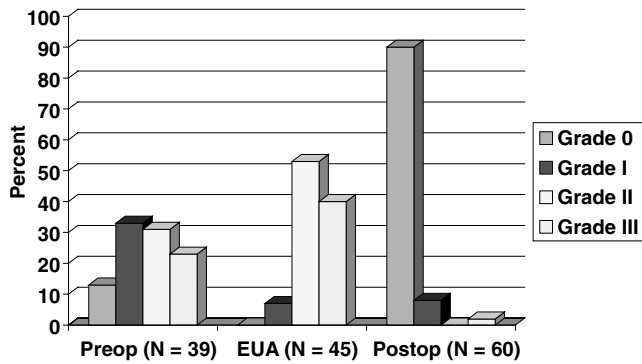
RESULTS

Of the 89 patients meeting eligibility criteria, 59 participated in this follow-up study (66% response rate). Of the 30 nonrespondents, 17 could not be located (19%), 8 declined participation (9%), 4 moved out of state (5%), and 1 was incarcerated (1%).

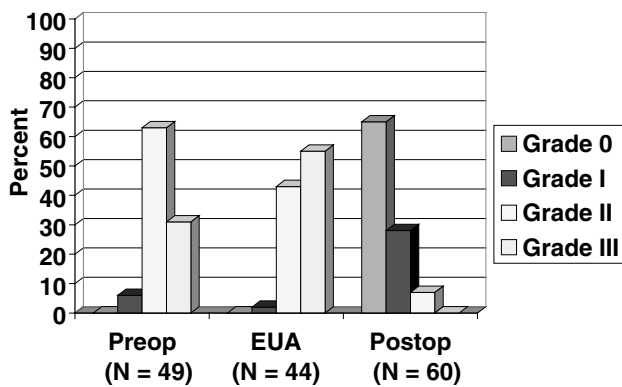
The average age of the 59 patients at the time of reconstruction was 41 years (range, 18-61 years; SD = 10). There were 21 male and 38 female patients, and there were 27 right knees and 33 left knees. One patient underwent single-stage bilateral reconstructions. The mean interval from the reconstruction to follow-up was 51 months (range, 26-170 months; SD = 27). The mean interval from injury to surgery was 65 months (range, 1-480 months; SD = 112). Fifty-six patients (95%; 57 knees) were reconstructed endoscopically, and 3 patients (5%) were reconstructed using a dual-incision technique.

Physical Examination

Results of preoperative ligament examinations, examinations under anesthesia, and postoperative examinations are depicted in Figure 1. The reduction in postoperative pivot shift grades from preoperative grades was statistically significant ($P < .001$). The decrease of postoperative Lachman test grades from the preoperative assessment was also statistically significant ($P < .001$). Using the IKDC definitions for total AP translation, 95% were normal and the remaining 5% were nearly normal. Postoperatively, the range of motion as measured by a goniometer was 140° (range, 122°-155°; SD = 8). The mean heel height difference after surgery in extension was 0.3 cm (range, 0-5 cm; SD = 1). Five patients (9%) had a heel height discrepancy of 2 cm or more. There was no statistically significant thigh girth atrophy measured in the reconstructed leg for the study group.



A



B

Figure 1. A, results of the pivot shift test grade assessments; B, results of the Lachman test grade assessments. EUA, examination under anesthesia.

Associated Procedures and Surgical Findings

Eighty-one percent of the patients (n = 42) had chondrosis present in at least 1 compartment at the time of surgery (see Table 1 for compartment stratification). There were no significant differences between the groups with and without chondrosis with regard to postoperative subjective and clinical scores. There were 17 prior surgeries performed, none of which involved ACL repair or reconstruction; 26 additional procedures were performed at the time of reconstruction, and 10 procedures were performed after reconstruction (Table 2).

Radiographic Results

Radiographs were obtained for 54 patients (5 were unable to undergo radiographic evaluation). Table 3 shows the results of the IKDC radiographic assessment. Staples were used for tibial fixation in 7% of patients (n = 4). Staple fixation was not associated with failures in this small group. Thirty-three patients (64%) were noted to have parallel placement of interference screws in both AP and lateral planes on the femur and tibia, and another 8

TABLE 1
Chondrosis Assessment by Involved Compartment at Surgery^a

	Present	1	2	3	4
Medial femoral condyle	37	2	10	23	2
Medial tibial plateau	22	7	3	12	0
Lateral femoral condyle	12	0	5	5	2
Lateral tibial plateau	22	12	3	5	2
Patella	53	8	20	23	2
Trochlea	22	3	5	12	2

^aIn percentages.

TABLE 2
Additional Injuries and Surgeries

Type of Injury or Surgery	No.
Prior Injury	
Patellar dislocation	2
Partial ACL tear	1
Prior surgeries	
Scope debridement	1
Lateral retinacular release (open)	1
Patellar proximal/medial soft tissue realignment	2
Partial medial meniscectomy	6
Partial lateral meniscectomy	4
Lateral meniscal repair	1
Medial collateral ligament repair	2
Concurrent procedures	
Partial medial meniscectomy	9
Medial meniscal repair	4
Partial lateral meniscectomy	11
Lateral meniscal repair	1
Microfracture of chondral defect	1
Subsequent procedures	
Partial medial meniscectomy	4
Partial lateral meniscectomy	1
Notch scar tissue removed	1
Painful hardware removal	3
High tibial osteotomy	1

patients (15%) had parallel placement in 3 of 4 planes. Six patients were noted to have interference screw divergence of >20° in either AP and/or the lateral plane (range, 20°-30°); this was noted on the femur in 5 patients (9%) and the tibia in 1 patient but did not correlate with failures or tunnel lucency or expansion.

Functional Examination

The functional parameters measured included a timed single-legged 6-m hop, a single-legged hop for distance, and a vertical jump. The single-legged hop of the affected knee was

TABLE 3
Postoperative International Knee Documentation
Committee Radiographic Assessment
by Compartment Involved and Severity^a

Compartment	Normal	Mild	Moderate	Severe
Medial compartment	70	17	9	4
Lateral compartment	91	4	4	2
Patellofemoral compartment	65	30	4	2

^aIn percentages.

98% of the performance of the unaffected knee overall (range, 70%-122%). Twenty-two patients (45%) performed better on the reconstructed knee, 11 (22%) had more than a 10% deficit of the unaffected leg's performance, and 5 patients (10%) tested the same on each leg. The average timed hop for the affected knee was 101% of the unaffected knee (range, 70%-145%). Seventeen patients (33%) performed better on the reconstructed knee, 7 (14%) had more than a 10% deficit of the unaffected leg's performance, and 11 (21%) were bilaterally equal. The vertical jump of the affected knee was on average 93% of the unaffected knee (range, 47%-157%). Thirteen patients (26%) performed better on the reconstructed knee, 21 (41%) had more than a 10% deficit of the unaffected leg's performance, and 7 (14%) were the same bilaterally. For the 3 tests, 78%, 87%, and 55% of the patients, respectively, had <10% side-to-side deficits on their affected knee.

Arthrometric Examination

Before Surgery. The KT-1000 arthrometric testing was recorded on 39 patients before surgery. The mean maximum manual translations of the affected knees were 14 mm (range, 6-21 mm; SD = 3) before surgery and 7.5 mm (range, 4-13 mm; SD = 2) for the unaffected knee. These differences were significant ($P < .001$). Stratification of side-to-side differences before surgery revealed that 15% had ≤ 3 -mm, 26% had 3.1- to 4.9-mm, and 59% had ≥ 5 -mm differences.

After Surgery. KT-1000 arthrometric testing was performed on all patients except 1 after surgery. The mean maximum manual translation was 7.6 mm (range, 4-16 mm; SD = 2) for the affected knee and 6.9 mm (range, 2-15 mm; SD = 2) for the unaffected knee. These improvements were significantly reduced compared to preoperative translations of the affected knee ($P < .001$). There were no significant differences between the reconstructed knee and nonaffected knee after surgery. Stratification of side-to-side differences after surgery revealed that 95% had ≤ 3 -mm side-to-side differences, and 5% had > 3 -mm but < 5 -mm side-to-side differences. The side-to-side reductions were statistically significant ($P = .001$).

Rating Scales and Subjective Results

Postoperative results of the IKDC, Lysholm, Tegner, current Noyes Sports Activity Scale, pain visual analog scale,

TABLE 4
Postoperative Knee Scoring Scales

Scale ^a	Mean	Range	Standard Deviation
IKDC	78	30-100	19
KOOS Pain	88	50-100	13
KOOS Symptom	84	46-100	14
KOOS ADL	94	62-100	9
KOOS Sports	78	0-100	25
KOOS Quality of Life	76	25-100	21
Tegner	6	2-10	2
Lysholm	82	43-100	17
Noyes Sports Activity	71	20-100	24
SF-12 Mental	53	23-63	9
SF-12 Physical	52	37-62	6
Pain visual analog scale	2	0-8	2

^aIKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcomes Score; ADL, Activities of Daily Living.

and SF-12 are outlined in Table 4. There were no statistically significant differences with regard to age or gender comparisons in any of the subjective outcome scales.

Ninety-four percent of the patients were completely or mostly satisfied with the results of their surgical procedure. Sixty-five percent were completely satisfied, 30% were mostly satisfied, 5% were somewhat satisfied, and no patients were dissatisfied. Ninety-six percent of the patients stated they would have the surgery again if the injury occurred to the opposite knee. Forty-six percent of the patients reported pain with stair climbing as mild or moderate. Two percent ($n = 1$) reported this pain as severe. Seventy-nine percent of the patients reported that they had no or mild difficulty kneeling. Eleven percent had moderate difficulty, 7% severe difficulty, and 4% extreme difficulty kneeling. There were no statistically significant differences in pain using stairs ratings or difficulty-kneeling ratings with regard to age or gender.

Rate of Failure

Failure was defined as the presence of a pivot shift test of any grade or KT-1000 arthrometer maximum manual test of ≥ 5 -mm side-to-side difference. Five patients had a grade I pivot shift, and 1 had a grade III pivot shift (10%). An additional patient who participated in intercollegiate basketball had a graft failure and was revised with another allograft; this knee was excluded from our analysis, but the patient was included in our failure data. The overall failure rate was 10%.

Complications

There were no infections, no evidence of any acute or chronic rejection of the grafts, and no evidence of disease transmission at the time of follow-up (no blood testing was performed). No patients had chronic effusions or synovitis. No patients had significant tunnel expansion (> 20 mm).

One patient was unable to attain full extension after surgery, and a cyclops lesion was debrided arthroscopically, after which full extension was achieved. After full asymptomatic recovery from the ACL reconstruction, 5 patients became symptomatic with meniscal abnormalities. Four subsequently underwent a partial medial meniscectomy and 1 a partial lateral meniscectomy. One patient who had a previous partial medial meniscectomy had a stable knee after ACL reconstruction but began having symptoms consistent with medial compartment arthritis. She underwent a high tibial osteotomy 18 months after her ACL reconstruction. Three patients had painful tibial hardware removed (Table 2).

DISCUSSION

ACL reconstruction after traumatic rupture has been demonstrated to prevent the loss of secondary stabilizers, damage to articular and meniscal cartilage, and progression to arthrosis due to recurrent instability in the athletic and physically active population.^{15,35} Bone-patellar tendon-bone autograft has been the most commonly used graft for ACL reconstruction, with stability success rates approaching 85% to 95%. Allograft tissue has been advocated as an alternative and has the benefit of no donor site morbidity, decreased operative time, smaller incisions, and a lower incidence of postoperative arthrofibrosis.³⁶ Allograft tissue has been shown to compare favorably both subjectively and functionally at intermediate and long-term follow-up compared to autograft.[†]

Chang et al noted comparable results between autograft and allograft reconstructions in a younger athletic population.¹³ The only statistically significant differences between their groups either subjectively or objectively was that the allograft group had a high rate of flexion contracture over 5°. There were 3 traumatic reruptures in the allograft group and none in the autograft group. This was not statistically significant, but the authors stated concern over this observation. Two studies have cautioned against the use of allograft tissue. Victor et al felt that the stability of the allograft reconstructions deteriorated over time,⁴⁹ and Stringham et al showed that the only statistically significant difference between their allograft and autograft groups was the rate of rerupture. There were 4 traumatic reruptures in their allograft group versus no reruptures in their autograft group.⁴⁶

There are limited studies in the literature with regard to ACL reconstruction in knees with preexisting chondrosis. Noyes and Barber-Westin conducted allograft bone-patellar tendon-bone ACL reconstruction on 40 patients with symptomatic arthrosis.³⁴ They found that not only was stability reliably restored, but the subjective arthritic symptoms and function also improved. These findings are confounded by the fact that 16 of 40 patients underwent revision ACL reconstruction. Shelbourne and Wilckens reported on 33 patients with symptomatic arthritis who underwent autograft ACL reconstruction.⁴³ They noted significant

improvement in subjective, functional, and arthrometric scores. They reported a 13% failure rate (>5-mm side-to-side difference), but this did not appear to affect patient subjective scores.

Although there has been evidence to suggest that there is an immune response to fresh-frozen allograft tissue,^{21,38} this did not appear clinically or radiographically in our patients and did not affect the short-term results in our study. Wilson et al recently reviewed the topic of tunnel enlargement after ACL surgery and stated, "Based on the current literature, it is difficult to conclude that there was an increased risk of tunnel lysis with allograft tissue as compared to autograft."^{51(p546)}

A significant potential risk associated with allografts is disease transmission, and recent cases of bacterial contamination in allograft tissues have raised concerns about the effectiveness of sterilization techniques.^{5,10,11,12} The estimated risk of human immunodeficiency virus (HIV) transmission has been calculated to be 1 in 1 600 000.¹¹ Viral transmission, such as HIV and hepatitis C virus (HCV), has been addressed with stringent prescreening and careful testing of allograft tissue before implantation, including polymerization chain reaction testing in addition to HIV and HCV antibody testing. To our knowledge, there have been no reports in the literature of HIV transmission since the initiation of polymerase chain reaction enzyme testing. Surgeons using allografts should "know" their tissue banks, and it is advisable that only accredited tissue banks that follow American Association of Tissue Banks protocols be used.

Several sterilization techniques have been employed to process allograft tissue. Low-dose gamma irradiation has been used typically between 20 and 30 kGy. These levels are adequate to kill surface bacteria, but doses in excess of 30 kGy are needed to be virucidal. Unfortunately, this level of irradiation has been shown to detrimentally affect the biomechanical strength of the graft.¹⁷⁻¹⁹

Chemical sterilization such as ethylene oxide has been shown to be effective at sterilizing the graft, but residue left on the graft after the sterilization process has been shown to cause an inflammatory reaction leading to chronic synovitis and graft failure.^{26,39,45} Although this methodology is no longer used, it is important to recognize that some of the historically referenced literature concluding that allografts are inferior used grafts sterilized with ethylene oxide.

Allograft incorporation is another concern. Autograft tissue undergoes a process of "ligamentization" whereby the graft is repopulated with native cells.² Early animal models showed good incorporation and no rejection phenomenon.^{4,16} Jackson et al demonstrated in a goat model that allograft healing took longer than in autografts.^{24,25} Recently, Malinin et al in a human retrieval study demonstrated central acellularity in grafts at 2 years after surgery.³⁰ Most investigators feel that it takes longer for an allograft to heal or ligamentize than an autograft.

Although there is conflicting evidence in the literature regarding outcomes with allograft reconstruction, our results compare favorably with our previously studied autograft cohort.⁶⁻⁸ The patients' rating of success was 92% mostly or completely satisfied in our autograft group ver-

[†]References 13, 22, 23, 28, 32, 37, 42, 44, 46.

TABLE 5
Comparison of Allograft Versus Autograft Experience at Rush Medical Center^a

	Bach et al (this article, allografts)	Bach et al ^{6,b}	Bach et al ^{7,c}	Bach et al ^{8,d}
Age, y	41 (range, 18-61)	27 (range, 16-45)	25 (range, 10-52)	26 (range, 12-53)
MMD-STs after surgery, %				
<3 mm	95	92	83	70
3-5 mm	5	4	14	26
>5 mm	0	4	3	4
Negative pivot shift, %	90	92	91	84
Pain with stair climbing, %				
Mild/moderate	46	NA	14	13
Severe	2	NA	0	0
Tegner	6.3 (range, 2-10)	6.3 (range, 1-9)	6.5 (range, 2-9)	6.3 (range, 2-9)
Lysholm	82 (range, 43-100)	88 (range, 52-100)	89 (range, 43-100)	87 (range, 34-100)
Noyes Sports Activity Scale	71 (range, 20-100)	90 (range, 50-100)	90 (range, 33-100)	89 (range, 27-100)
Would repeat surgery, %	96	95	95	94
Mostly or completely satisfied, %	94	90	92	97

^aMMD-STs, maximum manual difference side to side; NA, not applicable.

^bTwo- to 4-year retrospective follow-up (autografts).

^cMinimum 2-year retrospective follow-up (autografts).

^dFive- to 9-year retrospective follow-up (autografts).

was 94% in the allograft group. The positive pivot shift (grade I and higher) was present in 9% of our autograft group and 10% of the allograft group. In our autograft group, 74% had a negative Lachman test result versus 72% in the allograft group (Table 5).

In this study, KT-1000 arthrometric testing showed a significant reduction in maximum manual anterior translation and side-to-side differences at follow-up. There were no statistically significant differences between the affected and unaffected knees after surgery with regard to arthrometric testing.

In our study, there was a significant difference in the degree of chondrosis present at the time of the reconstruction compared to our autograft cohort.⁶⁻⁸ There was some degree of chondrosis in at least 1 compartment in 50% of our autograft group and 78% in the allograft group. This could be related to the fact that the average age at the time of reconstruction for our autograft group was 26 years (range, 10.4-52.7 years; SD = 9) versus 41 years (range, 18-61 years; SD = 10) in the allograft group. Subjectively, 14% of the autograft group had mild pain associated with ascending or descending stairs versus 46% in the allograft group. There were no significant differences in subjective complaints of pain between those with and those without chondrosis before surgery.

The concern over rerupture of the allograft that was expressed in other studies has not yet occurred in our series. Indelicato et al reported a 7% failure rate in their study of primary allograft ACL reconstructions.²³ One failure met criteria by KT-1000 arthrometer measurements and 2 failures were traumatic reruptures. There was no statistically significant difference in this rate compared to a matched autograft cohort. Stringham et al reported a 13% rerupture rate in their allograft group and none in their autograft group.⁴⁶ All of the reruptures were trau-

matic, but there was no significant difference between the groups. Chang et al reported a 6.5% rerupture rate occurring in their allograft reconstructions versus no reruptures in their autograft group.¹³ Although this also failed to reach statistical significance, the authors stated that their numbers did not achieve adequate power.

In this select population, nonirradiated patellar tendon grafts overall were objectively and subjectively comparable to our historic autograft controls performed endoscopically or with a dual incision. Comparing these groups, there were no statistically significant differences in postoperative Lachman test grade or pivot shift grade, KT-1000 arthrometer maximum manual side-to-side differences or affected knee translations, range of motion, postoperative Tegner rating scales, or subjective satisfaction levels. Significant differences in the incidence of patellar pain in our allograft group were noted, but this was reflective of the significantly older age population and significantly higher incidence of patellofemoral chondrosis noted at reconstruction and biased by our recommendation to consider an allograft reconstruction in those patients who before surgery had significant patellar symptoms or crepitation. The Noyes Sports Activity Scale was significantly lower in our allograft series, again reflective of a selection bias and the older age of this population. In the allograft group, there was an increased incidence of articular surface abnormalities as well as preoperative degenerative joint disease; again, this is reflective of our selection bias and the older patient population.

The potential weaknesses of this study are that it was retrospective, nonrandomized, and lacked prospective data for the various scoring scales. Our follow-up retrieval rate is also subject to criticism. Graft selection and the accelerated rehabilitation protocol were not randomized (selection bias). We did not have a control group, but there have

been several retrospective studies of patellar tendon autograft reconstruction conducted by the senior authors (B.R.B. and C.B.J.) using a similar technique with autograft from our institution, which provides a historical perspective.⁶⁻⁸ The use of the patellar tendon allograft may reflect a surgeon's selection bias. Finally, the relatively minimum follow-up of 2 years has been expressed as a concern by some authors. However, the mean follow-up interval was 51 months. In this study, 81% of the patients had a follow-up period between 24 and 60 months, and 19% had more than 5 years of follow-up. Longer-term follow-up is planned, but at our current follow-up interval, rerupture of the allografts has not yet occurred.

There are multiple strengths of this study. Only fresh-frozen, nonirradiated bone-patellar tendon-bone allograft tissue was used. All grafts were obtained from a single tissue bank. Multiple validated outcome scores were used, including the IKDC, KOOS, and SF-12. Preoperative and postoperative KT-1000 arthrometer testing and functional testing were performed by 1 experienced athletic trainer to prevent detection bias. Patients independently filled out the subjective questionnaires. The physical examinations were performed by an orthopaedic fellow independent of the surgeons. However, the senior surgeons did personally evaluate the majority of these patients (>80%) for accuracy purposes; in no patient did our examination grading for the Lachman or pivot shift tests differ. Two experienced knee ligament surgeons who have performed more than 2000 primary ACL reconstructions performed all the operations.

In conclusion, this study has shown that subjective improvement, functional improvement, and objective measures of stability were successfully restored with fresh-frozen, nonirradiated bone-patellar tendon-bone allograft for ACL reconstruction in the patients selected for this procedure. These results are comparable to our previous autograft cohort and significantly better than our experience using nonirradiated allograft for revision ACL surgery for a failed primary patellar tendon autograft. Our patients did have significantly more preexisting chondrosis than the autograft group, and this did increase the subjective complaints of pain after surgery. Our results indicate that the use of allograft tissue for ACL reconstruction is a viable alternative to autograft in the patient population we selected; however, the patient with preexisting articular damage must be counseled about realistic expectations and the possibility of future arthritic symptoms.

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