Anterior Cruciate Ligament Reconstruction Using Patellar Tendon Allograft: An Age-Dependent Outcome Evaluation

F. Alan Barber, M.D., Jorge Aziz-Jacobo, M.D., and Fernando Barrera Oro, M.D.

Purpose: To compare the outcomes of a consecutive series of nonrevision bone–patellar tendon–bone (BPTB) allograft anterior cruciate ligament (ACL) reconstructions in patients aged 40 years or older and patients aged younger than 40 years. **Methods:** Prospectively collected data from consecutive BPTB allograft ACL reconstructions fixed with biodegradable interference screws and performed by a single surgeon were analyzed by use of established outcome measures. Preoperative and postoperative outcome assessments included Cincinnati, Lysholm, and Tegner scores and International Knee Documentation Committee (IKDC) activity scores. Lachman test, pivot-shift test, and KT arthrometer (MEDmetric, San Diego, CA) measurements were obtained at a minimum of 24 months after surgery. **Results:** In total, 32 patients met the inclusion criteria (21 men and 11 women). The mean follow-up was 35 months (range, 24 to 58 months). Of the patients, 21 were aged younger than 40 years (66%) and 11 were aged 40 years or older (34%). The mean age was 35 years (range, 18 to 55 years). In patients aged younger than 40 years, the mean postoperative Cincinnati score was 82.4 (39.1 preoperatively); Tegner score, 6.2 (3.9 preoperatively); Lysholm score, 89.5 (46.8 preoperatively); and IKDC activity score, 2.7 out of 4 (1.7 preoperatively). Five patients had a positive postoperative Lachman test, but none had a positive pivot-shift test. KT examinations showed a manual maximum difference of less than 3 mm in all but 1 patient (mean, 0.7 mm). In patients aged 40 years or older, the mean postoperative Cincinnati score was 83.8 (44.4 preoperatively); Tegner score, 6.6 (3.9 preoperatively); Lysholm score, 88.8 (50.1 preoperatively); and IKDC activity score, 2.7 out of 4 (2.1 preoperatively). One patient had a positive postoperative Lachman test, but none had a positive pivot-shift test. KT examinations showed a manual maximum difference of less than 3 mm in all but 1 patient (mean, 1.3 mm). **Conclusions:** The outcomes of BPTB allograft ACL reconstructions were not different both subjectively and objectively for patients aged 40 years or older and patients aged younger than 40 years. BPTB allograft ACL reconstruction provides consistent results for patients of all age groups. **Level of Evidence:** Level III, retrospective comparative study.

Anterior cruciate ligament (ACL) reconstruction is a common procedure that can be performed with a variety of tissue grafts. To avoid problems related to graft harvesting, allogeneic tissue has been used as a graft for ACL reconstructions. ACL reconstructions have reported success rates of 85% to 95%.[1] The bone–patellar tendon–bone (BPTB) autograft is a common choice because of its low rate of graft failure and good clinical outcomes.[2-5] Allograft options also exist and include BPTB and Achilles, tibialis anterior, fascia lata, hamstring, and quadriceps tendons.[6-9] Good clinical results have been reported with the use of BPTB allograft with 2 to 5 years of follow-up, with BPTB allograft comparing favorably with BPTB autograft,[2,7-9] and no higher rate of bacterial infection has been observed in ACL reconstructions when allograft tissue is used.[10]

Allograft ACL reconstructions have been shown to be beneficial in patients with post-traumatic arthrosis.[11] The results of allograft reconstruction in patients aged over 40 years have been reported to be satisfactory, although this comparison used historical controls.[12] Older patients are unwilling to accept knee

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instability and prefer to undergo ACL surgery to allow them to continue their participation in pivoting activities.[13] However, a recent survey of the membership of the Arthroscopy Association of North America indicated that surgeons are more likely to select a patellar tendon autograft for younger patients and a patellar tendon allograft for older patients.[14] This suggests a bias that may be based on the belief that an allograft may not perform as well in the younger age group. The purpose of this study was to compare the outcomes of a consecutive series of nonrevision BPTB allograft ACL reconstructions in patients aged 40 years or older and patients aged younger than 40 years. The hypothesis of this study was that a BPTB allograft ACL reconstruction would provide results independent of age group.

METHODS

All BPTB allograft ACL reconstructions performed by the senior author (F.A.B.) from 2002 to 2005 were evaluated. The data were prospectively collected at each patient visit and the protocol for this study established at the beginning of the study period. The data were then retrospectively reviewed after sufficient data were collected. Patients chose either a patellar tendon allograft or autograft after a thorough explanation of treatment options including the nature of the procedure, postoperative rehabilitation protocols, incision size, and potential risks. Harner et al.[3] pointed out that patients must be involved in this selection process because of the inherent risks and different benefits of either option, making true randomization very difficult to achieve. The patients selecting an allograft reconstruction were grouped based on age into 2 groups: those aged younger than 40 years and those aged 40 years or older.

Inclusion criteria were a positive Lachman test and pivot-shift test, closed or nearly closed growth plates based on radiographs, a minimum follow-up of 24 months, and patient selection of the allograft procedure after thorough counseling and giving informed consent. Concomitant meniscal and chondral injuries, as well as healed grade 1 or 2 collateral ligament sprains, were allowed. Exclusion criteria included prior ACL reconstruction of the knee requiring a revision procedure, associated posterior cruciate ligament tears, or multiple-ligament injuries.

Preoperative and postoperative assessments included a history; physical examination; radiographs; preoperative Cincinnati,[15] Lysholm,[16] and Tegner[17] knee scores; and International Knee Documentation Committee (IKDC) activity scores. The physical examination included supine goniometer-measured range of motion, Lachman test, pivot-shift test, and KT arthrometer (MEDmetric, San Diego, CA) measurements. Patient evaluations were performed at 3, 6, 12, and 24 months and then annually thereafter. Laxity was graded as trace (1 to 3 mm), 1+ (4 to 5 mm), 2+ (5 to 10 mm), or 3+ (>10 mm). The pivot-shift sign was graded as 1+ (glide), 2+ (clunk), or 3+ (gross subluxation) in the position of thigh abduction and external rotation, which makes this sign more evident.[18] Side-to-side manual maximum KT differences were obtained. The follow-up physical examinations were performed by an independent examiner who was not the surgeon to reduce observer bias. Results were stratified and scored as excellent when the difference was less than 3 mm and good when the difference was 3 to 5 mm. Differences over 5 mm were considered failures.

All patients had radiographs obtained at the initial postoperative clinical visit that confirmed tunnel placement, along with bone plug and interference screw location. Radiographs taken at subsequent visits were compared with those obtained immediately after surgery to assess changes and to evaluate healing progress.

Surgical Technique

All patients underwent an examination under anesthesia, and all had a positive Lachman test and pivot-shift test. Graft preparation was started simultaneously with the arthroscopic procedure and was performed by either a certified physician assistant or arthroscopic surgery sports fellow. A fresh-frozen, entire-donor, low dose–irradiated (1.2 to 1.8 megarads), hemi-BPTB graft was prepared by contouring the tibia into a 10-mm bullet-shaped plug and the patellar graft into a 9-mm bullet-shaped piece. When possible, the tendon width was cut to 15 mm (Fig 1) and the bone plugs were 25 mm long (Fig 2). The arthroscope was placed through a central, trans–patellar tendon portal and diagnostic arthroscopy performed. If a meniscus tear or chondral lesion was encountered, it was addressed before the ACL surgery. An appropriately sized intercondylar notchplasty was performed. The tibial tunnel was made with a tibial guide inserted into the stump of the ACL on the tibia, a guidewire advanced through an aiming device, and a tibial tunnel drilled with a 10-mm cannulated reamer. Through this tunnel, a transtibial aiming guide was advanced to the appropriate position on the superior-lateral side of the

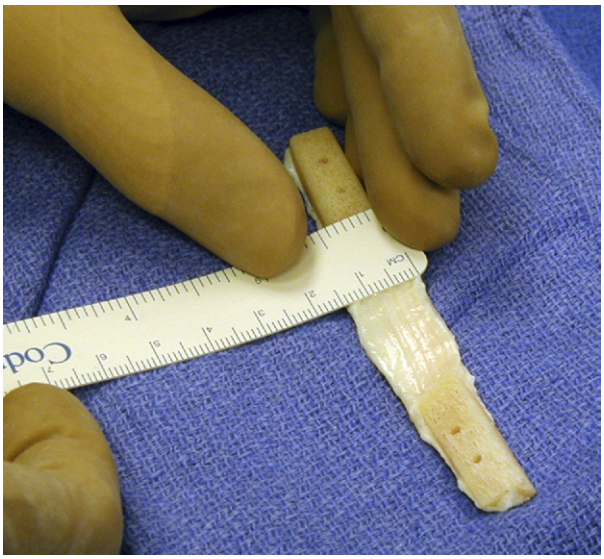

Figure 1. BPTB allografts were created with a 10-mm-wide tibial plug and 9-mm-wide bullet-shaped patellar plug. When possible, the tendon width was cut to 15 mm.

intercondylar notch. A guidewire was passed through this transtibial aiming device to engage the lateral femoral cortex. The aiming device was removed and a 9-mm reamer advanced over the guidewire to a depth of 3 to 4 cm. The sutures attached to the proximal patella bone plug were threaded through the guidewire and pulled through the lateral side of the thigh, advancing the entire graft into position. Appropriately sized and selected biodegradable interference screws were used to secure the graft into position in the femur and the tibia.

All allograft tissues were recovered in an aseptic fashion in the operating room or other facilities with similar environments and maintained as such throughout their processing and distribution. The whole donors were exposed before harvesting to a low dose (1.2 to 1.8 megarads) of gamma radiation as a means of reducing the surface bioburden. Cultures of the harvested patellar tendon allograft specimens were then taken. Any specimen showing a positive tissue culture taken at the time of harvest was subsequently re-treated with low-dose gamma radiation. None of the grafts implanted in this series of cases received a second irradiation treatment.

Postoperative Management

Postoperative management focused initially on achieving full extension compared with the opposite leg by prone hangs and bridging exercises. Progressive weight bearing with the elimination of crutches within 1 to 2 weeks was encouraged. Motion was initially limited by a postoperative brace, and flexion was gradually increased to 30° at week 1 and 60° at week 2, with flexion to 90° by week 4 and full flexion at week 6; the brace was removed at week 8. Postoperative continuous-flow cold therapy was used to reduce swelling and pain.

Stationary bicycling was started at 8 weeks and straight-ahead running at 12 weeks. A return to pivoting sports protected by a derotational knee brace was allowed at 5 to 6 months if adequate strength was regained.

Statistical Analysis

A paired *t* test was performed to analyze the differences between preoperative and postoperative clinical measures and comparisons between the group aged younger than 40 years and the group aged 40 years or older. Statistical significance was achieved at $P < .05$.

RESULTS

In the study period 32 consecutive patients underwent arthroscopic BPTB allograft ACL reconstruction with interference screw fixation at both the femoral and tibial ends and met the inclusion criteria. Seven revision ACL reconstructions in the group aged

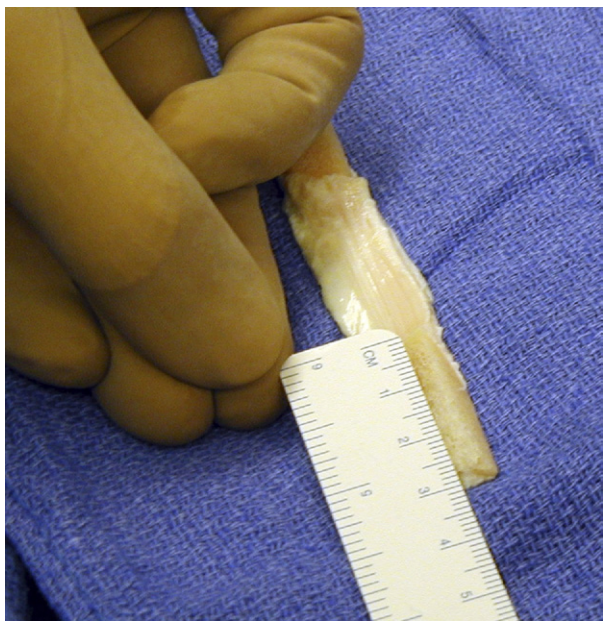

Figure 2. Bone plug lengths were cut to 25 mm.

TABLE 1. *Comparison of Objective Data Between Allograft Reconstructions in Patients Aged 40 Years or Older and Patients Aged Younger Than 40 Years at Time of Surgery*

	Lachman*				Pivot Shift†				KT Examination‡			
	0	1+	2+	3+	0	1+	2+	3+	<3 mm	3-5 mm	>5 mm	Mean Manual Maximum Difference
<40 yr	18	2	1	0	20	0	1	0	20	1	0	0.7 mm
≥40 yr	10	1	0	0	11	0	0	0	10	0	1	1.3 mm

*$P = .41$.
†$P = .48$.
‡$P = .38$.

younger than 40 years and four in the group aged 40 years or older were performed during this interval and excluded. Of the patients, 21 were aged younger than 40 years (66%) and 11 were aged 40 years or older (34%). The mean age for those aged younger than 40 years was 31 years (range, 18 to 39 years; median, 32 years). The mean age for those aged 40 years or older was 46 years (range, 40 to 55 years; median, 46 years). There were 21 men and 11 women. The right knee was involved in 19 patients and the left in 13. The mean follow-up was 35 months (range, 24 to 58 months). The mean age was 35 years (range, 18 to 55 years). The ACL reconstruction was performed on an acute basis in 80% of the group aged younger than 40 years and in 73% of the group aged 40 years or older.

Physical examinations, along with radiographic and KT evaluations, were performed in all patients. In the group aged younger than 40 years, the mean Cincinnati score of 39.1 (range, 6 to 82) preoperatively improved to 82.4 (range, 54 to 95) after surgery. The Tegner score increased from a mean preoperative score of 3.9 (range, 1 to 7) to a mean postoperative score of 6.2 (range, 3 to 10). The Lysholm score improved from a mean preoperative score of 46.8 (range, 2 to 88) to a mean postoperative score of 89.5 (range, 59 to 100). The IKDC activity score increased from a mean of 1.7 preoperatively to 2.7 out of 4 postoperatively. All of these increases from the preoperative state were statistically significant ($P = .0001$).

In the group aged 40 years or older, the mean Cincinnati score of 44.4 (range, 9 to 60) preoperatively improved to 83.8 (range, 47 to 95) postoperatively. The Tegner score increased from a mean preoperative score of 3.9 (range, 2 to 8) to a mean postoperative score of 6.6 (range, 2 to 9) ($P = .05$). The Lysholm score improved from a mean preoperative score of 50.1 (range, 21 to 71) to a mean postoperative score of 88.8 (range, 54 to 100). The IKDC activity score increased from a mean of 2.1 preoperatively to 2.7 out of 4 postoperatively ($P = .1$). Except where indicated, these increases were statistically significant at a level of $P < .0001$.

The results of the postoperative physical examinations including Lachman and pivot-shift testing are reported in Table 1. No statistical differences existed between these 2 groups for any of these objective tests.

Supine flexion and extension goniometer measurements showed that 3 of 32 patients had an extensor lag (did not achieve full extension as measured against the opposite normal knee). These measured 2°, 3°, and 5°. If loss of extension is defined as a greater than 5° side-to-side difference in passive knee extension,[19] then no loss of extension was observed. Every patient achieved at least 110° of flexion, and mean flexion was 134° (range, 110° to 155°). KT examination at follow-up showed a mean manual maximum difference of 1.3 mm for the group aged younger than 40 years and 1.4 mm for the group aged 40 years or older.

Radiographic assessments showed visible bone plug incorporation at final follow-up and as early as 12 months after surgery. There were no clinical symptoms to suggest graft infection.

DISCUSSION

Because ACL reconstruction is becoming more common in older age groups, allografts are being selected with increasing frequency. Individuals aged 40 years or older are continuing to participate in intensive pivoting activities for which a functional ACL is essential. Although nonoperative treatment has been shown to be effective in appropriately selected individuals,[20] individuals aged 40 years or older are not eager to accept activity-related knee instability and consequently request ACL surgery despite the surgical risks.[13]

Both allografts and autografts provide initial strength through a fibrous framework for later ligamentous healing.[21] Although the maximal tensile

strength of allografts is less than that of autografts,[22] allograft tissues reach maturity more slowly than autograft tissues,[23] and allograft tendons have a slower onset and rate of revascularization,[24] postsurgical allograft thigh muscle power as measured by knee extension torque is significantly better than that of postsurgical autografts.[25] Although allograft tissue represents an expense in the reconstructive procedure, a cost-comparison study between autograft and allograft ACL reconstructions showed that allograft procedures were less expensive.[26] In the current reimbursement climate, which is shifting more costs to the patient, a postoperative program that can be self-administered (i.e., allograft ACL) and consequently avoid physical therapy visits with their attendant copay costs could significantly reduce the out-of-pocket expense to the patient.

Previous comparisons of the significance played by patient age in ACL reconstruction showed no statistical difference in outcomes between those aged 40 years or older and those aged younger than 40 years treated with BPTB autografts.[27] Excellent or good Lysholm scores were recorded in 89% of the group aged 40 years or older and 91% of the group aged younger than 40 years.[27] Several studies have failed to show a significant difference in outcomes between patellar tendon allograft and autograft reconstructions.[3-5,11,28] This led to our hypothesis that a BPTB allograft ACL reconstruction would provide results independent of age.

To test this hypothesis, a comparison of BPTB allograft ACL reconstruction in 2 groups (patients aged $\geq$40 years and patients aged $<$40 years) was conducted. Statistically significant improvements occurred from the preoperative status to the postoperative status for both groups by use of validated measurement scales (Lysholm, Cincinnati, and Tegner scores and IKDC activity scores). Objective measures failed to show a difference in the 2 groups (Lachman test, pivot-shift test, and KT maximum manual difference) and supported our hypothesis.

The potential weaknesses of this study are that this was a retrospective review of prospectively collected data. Because the patients selected the use of the allograft, a selection bias must be considered.

CONCLUSIONS

The outcomes of BPTB allograft ACL reconstructions were not different both subjectively and objectively for patients aged 40 years or older and patients aged younger than 40 years. BPTB allograft ACL reconstruction provides consistent results for patients of all age groups.

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REFERENCES

1. Bach BR Jr, Aadalen KJ, Dennis MG, et al. Primary anterior cruciate ligament reconstruction using fresh-frozen, nonirradiated patellar tendon allograft: Minimum 2-year follow-up. *Am J Sports Med* 2005;33:284-292.
2. Baer GS, Harner CD. Clinical outcomes of allograft versus autograft in anterior cruciate ligament reconstruction. *Clin Sports Med* 2007;26:661-681.
3. Harner CD, Olson E, Irrgang JJ, Silverstein S, Fu FH, Silbey M. Allograft versus autograft anterior cruciate ligament reconstruction: 3- to 5-year outcome. *Clin Orthop Relat Res* 1996: 134-144.
4. Chang SK, Egami DK, Shaieb MD, Kan DM, Richardson AB. Anterior cruciate ligament reconstruction: Allograft versus autograft. *Arthroscopy* 2003;19:453-462.
5. Peterson RK, Shelton WR, Bomboy AL. Allograft versus autograft patellar tendon anterior cruciate ligament reconstruction: A 5-year follow-up. *Arthroscopy* 2001;17:9-13.
6. Gasser S, Uppal R. Anterior cruciate ligament reconstruction: A new technique for Achilles tendon allograft preparation. *Arthroscopy* 2006;22:1365.e1-1365.e3. Available online at www.arthroscopyjournal.org.
7. Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. *Arthroscopy* 2008; 24:292-298.
8. Marrale J, Morrissey MC, Haddad FS. A literature review of autograft and allograft anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2007;15: 690-704.
9. Poehling GG, Curl WW, Lee CA, et al. Analysis of outcomes of anterior cruciate ligament repair with 5-year follow-up: Allograft versus autograft. *Arthroscopy* 2005;21:774-785.
10. Katz LM, Battaglia TC, Patino P, Reichmann W, Hunter DJ, Richmond JC. A retrospective comparison of the incidence of bacterial infection following anterior cruciate ligament reconstruction with autograft versus allograft. *Arthroscopy* 2008;24: 1330-1335.
11. Noyes FR, Barber-Westin SD. Arthroscopic-assisted allograft anterior cruciate ligament reconstruction in patients with symptomatic arthrosis. *Arthroscopy* 1997;13:24-32.
12. Kuechle DK, Pearson SE, Beach WR, et al. Allograft anterior cruciate ligament reconstruction in patients over 40 years of age. *Arthroscopy* 2002;18:845-853.
13. Seng K, Appleby D, Lubowitz JH. Operative versus nonoperative treatment of anterior cruciate ligament rupture in patients aged 40 years or older: An expected-value decision analysis. *Arthroscopy* 2008;24:914-920.
14. Karzel RP. Results of ACL graft choice survey. *Inside AANA* 2009;25:11.
15. Noyes FR, Barber SD, Mooar LA. A rationale for assessing sports activity levels and limitations in knee disorders. *Clin Orthop Relat Res* 1989:238-249.
16. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. *Am J Sports Med* 1982;10:150-154.
17. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res* 1985:43-49.

18. Bach BR Jr, Warren RF, Wickiewicz TL. The pivot shift phenomenon: Results and description of a modified clinical test for anterior cruciate ligament insufficiency. *Am J Sports Med* 1988;16:571-576.
19. Mauro CS, Irrgang JJ, Williams BA, Harner CD. Loss of extension following anterior cruciate ligament reconstruction: Analysis of incidence and etiology using IKDC criteria. *Arthroscopy* 2008;24:146-153.
20. Ciccotti MG, Lombardo SJ, Nonweiler B, Pink M. Nonoperative treatment of ruptures of the anterior cruciate ligament in middle-aged patients. Results after long-term follow-up. *J Bone Joint Surg Am* 1994;76:1315-1321.
21. Kuhn MA, Ross G. Allografts in the treatment of anterior cruciate ligament injuries. *Sports Med Arthrosc* 2007;15:133-138.
22. Shino K, Kawasaki T, Hirose H, Gotoh I, Inoue M, Ono K. Replacement of the anterior cruciate ligament by an allogeneic tendon graft. An experimental study in the dog. *J Bone Joint Surg Br* 1984;66:672-681.
23. Shino K, Inoue M, Horibe S, Nagano J, Ono K. Maturation of allograft tendons transplanted into the knee. An arthroscopic and histological study. *J Bone Joint Surg Br* 1988; 70:556-560.
24. Muramatsu K, Hachiya Y, Izawa H. Serial evaluation of human anterior cruciate ligament grafts by contrast-enhanced magnetic resonance imaging: Comparison of allografts and autografts. *Arthroscopy* 2008;24:1038-1044.
25. Shino K, Nakata K, Horibe S, Inoue M, Nakagawa S. Quantitative evaluation after arthroscopic anterior cruciate ligament reconstruction. Allograft versus autograft. *Am J Sports Med* 1993;21:609-616.
26. Cole DW, Ginn TA, Chen GJ, et al. Cost comparison of anterior cruciate ligament reconstruction: Autograft versus allograft. *Arthroscopy* 2005;21:786-790.
27. Barber FA, Elrod BF, McGuire DA, Paulos LE. Is an anterior cruciate ligament reconstruction outcome age dependent? *Arthroscopy* 1996;12:720-725.
28. Stringham DR, Pelmas CJ, Burks RT, Newman AP, Marcus RL. Comparison of anterior cruciate ligament reconstructions using patellar tendon autograft or allograft. *Arthroscopy* 1996; 12:414-421.