Revision Rates After Anterior Cruciate Ligament Reconstruction Using Bone–Patellar Tendon–Bone Allograft or Autograft in a Population 25 Years Old and Younger

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Purpose: To compare clinical outcomes and revision rates for anterior cruciate ligament (ACL) reconstructions using bone–patellar tendon–bone (BPTB) allografts versus BPTB autografts in a population of patients aged 25 years and younger. **Methods:** A consecutive series of patients 25 years or younger undergoing ACL reconstruction with either a patient-selected BPTB allograft or BPTB autograft fixed with biocomposite interference screws was retrospectively reviewed. Multiligamentous and posterior cruciate ligament tears were excluded. All allografts were from a single source and not chemically processed or irradiated. Two graft-specific rehabilitation programs were used. The primary outcome measure was graft failure. Failure was defined as a subsequent ACL revision surgery, 2+ Lachman test, positive pivot-shift, or side-to-side KT difference of greater than 5 mm. Secondary outcome measures included Cincinnati, Lysholm, and International Knee Documentation Committee (IKDC) activity scores. **Results:** In 81 patients at least 24 months after surgery (28 allografts; 53 autografts), 7 failures were identified: 2 of 28 (7.1%) allografts and 5 of 53 (9.4%) autografts. Mean Cincinnati scores improved from 54.6 and 39.5 (allografts and autografts, respectively) to 86.2 and 85.1. Mean Lysholm scores improved from 60.3 and 44.8 (allografts and autografts, respectively) to 89.9 and 87.0. Average KT differences were 0.59 mm (allograft) and 0.34 mm (autograft group) ($P = .58$). IKDC activity scores were 2.9 (allografts) and 3.1 (autografts) postoperatively ($P = .32$). **Conclusions:** Using a patient-choice ACL graft selection program after appropriate counseling and using graft-specific rehabilitation programs, not chemically processed or irradiated BPTB allograft reconstructions have no greater failure rate than autografts in patients aged 25 years and younger at a minimum 2-year follow-up. No significant differences in Cincinnati, Lysholm, and IKDC activity scores were found between these 2 groups. **Level of Evidence:** Level III, retrospective comparative study.

The number of anterior cruciate ligament (ACL) ruptures in young but skeletally mature patients continues to rise.[1,2] Failure to effectively stabilize the knees of these young patients can lead to an increase in meniscal tearing, osteochondral lesions,[3] and early degenerative joint disease.[4] Controversy exists concerning the appropriate graft choice for ACL reconstruction in this particular patient population.[5] Historically, both autograft and allograft options have been reported to demonstrate similar successful outcomes.[6-8] Additionally, the use of allograft material in populations older than age 25 is generally accepted for ACL reconstruction. However, some studies report a higher failure rate using allograft material compared with autograft material of the same type for ACL reconstruction in those younger than age 25.[9,10] Other studies suggest the issue is not the graft material but differing activity levels[11] or graft processing.[2] Allograft preparation can have a significant effect on outcome. Irradiation or chemical processing of allografts may result in an increased incidence of graft rupture.[12] Harsh sterilization techniques[13] and higher doses of radiation are known to have a deleterious effect on allografts.[14,15]

Patient selection is a key element in graft choice. A recent study reported no significant difference in function, activity, or satisfaction between allograft and autograft reconstructions in a younger patient population, although the allograft group had a much higher failure rate than the autograft group.[2] The purpose of this study was to compare clinical outcomes and revision

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The authors report the following potential conflict of interest or source of funding: F.A.B. receives support from DePuy-Mitek, Linvatec, and Arthrex.

Received July 21, 2013; accepted December 31, 2013.

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0749-8063/13509/$36.00

http://dx.doi.org/10.1016/j.arthro.2013.12.022

rates for ACL reconstructions using bone—patellar tendon—bone (BPTB) allografts versus BPTB autografts in a population of patients aged 25 and younger. The hypothesis was that there is no difference in outcomes or revision rates between the 2 graft options at a minimum follow-up of 24 months.

Methods

With institutional review board approval, a consecutive series of patients undergoing ACL reconstruction with either a BPTB allograft or BPTB autograft fixed with biocomposite (Milagro, DePuy-Mitek, Raynham MA) interference screws on both ends was retrospectively reviewed.

Inclusion criteria were patients 25 years or younger undergoing an ACL reconstruction with radiographically proven closed or nearly closed growth plates and a minimum follow-up of 24 months. Patients with a history of patellar tendinopathy, jumper's knee, or Osgood Schlatter's disease, and participants in sports including high jump, team handball, and basketball were included. Revision surgery was not an exclusion criterion. Exclusion criteria were posterior lateral corner injuries, posterior cruciate ligament tears, or fractures.

Graft selection (allograft or autograft) (nonrandomized) was determined by the patient after a thorough explanation of the patellar tendon allograft and autograft treatment programs, including the nature of the procedure, postoperative rehabilitation protocols, speed of return to work and sports, incision size, and potential risks associated with the inherent differences and benefits of these 2 options.

Surgical Technique

If a BPTB autograft was used, it was harvested at the beginning of the procedure and the patellar tendon defect closed. Any excess bone from the graft was used to fill the patellar defect. If a BPTB allograft was used, it was prepared in the same manner as an autograft. No tourniquet was used for the allograft procedures, and a tourniquet was used only during graft harvest for the autografts.

After an examination under anesthesia, a complete arthroscopic knee examination was performed. Any associated injuries were noted and treated, including addressing areas of chondral damage and loose bodies. Meniscal tears were assessed and debrided or repaired if appropriate, usually using an all-inside technique.

A central patellar tendon viewing portal was used in all cases because it allows excellent visualization of the anatomic ACL attachment site and avoids the need to switch the arthroscope between medial and lateral portals. If needed, an intercondylar notchplasty was performed. A transtibial technique was used for all cases. The tibial tunnel was made with a tibial guide inserted into the debrided tibial ACL footprint. This guide was positioned so that the tibial cortex was broached immediately anterior to the superficial medial collateral ligament near the superior border of the pes anserine. This location creates a tunnel angle allowing adequate access to the ACL femoral attachment site.[16] The intra-articular aiming point for the tibial guidewire was in the center of the previous tibial ACL attachment site immediately anterior to the posterior edge of the anterior horn of the lateral meniscus.

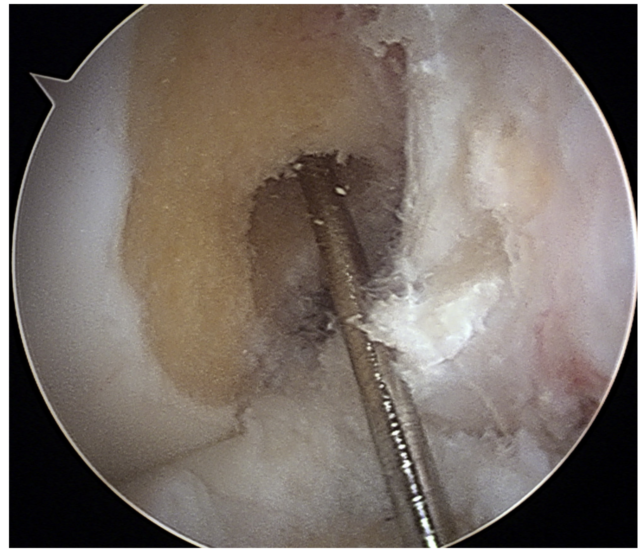

Fig 1. A transtibial guidewire is shown passed through the tibial tunnel into the femoral ACL attachment site (right knee flexed 90° viewed through an arthroscopic central portal). © F. Alan Barber, M.D.

With the knee flexed at 90°, a guidewire was advanced through the tibial aiming device and then over-drilled with a 10-mm cannulated reamer to create the tibial tunnel. Through this tibial tunnel, a transtibial aiming guide (either 6 or 7 mm offset depending on patient size) was advanced to the appropriate position on the superior lateral side of the intercondylar notch. Rotation of the transtibial guide within the tibial tunnel allowed reaching a lower position on the lateral condyle face to target the normal ACL femoral attachment site. A guidewire was passed through this transtibial aiming device exiting the lateral femoral cortex. After removing the transtibial aiming device, a 9-mm cannulated reamer was advanced over the guidewire to create a femoral tunnel 3 cm deep (Fig 1).

The proximal patellar bone plug sutures were threaded through the guidewire and pulled out the lateral thigh advancing the entire graft into position. Appropriately sized biocomposite interference screws secured the graft into position in the femur and the tibia (Fig 2). The femoral screw was placed on the anterior aspect of the femoral bone plug to keep the graft posteriorly

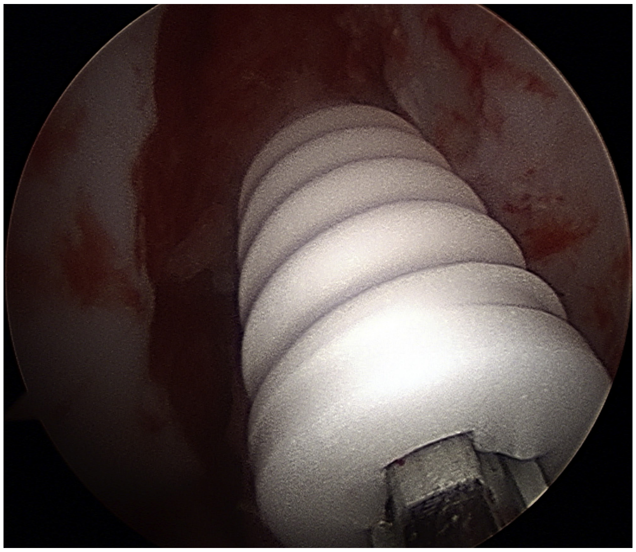

Fig 2. The biocomposite Milagro interference screw secures the graft into position in the femur (right knee flexed 90° viewed through an arthroscopic central portal). © F. Alan Barber, M.D.

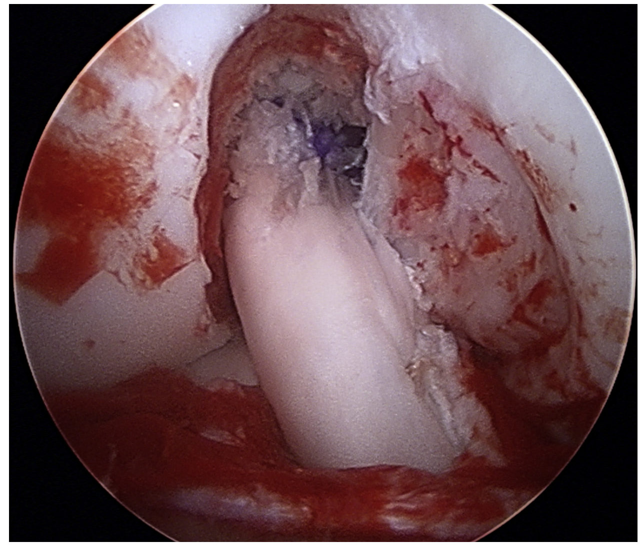

Fig 3. The tendon portion of an allograft was wrapped with platelet-rich fibrin membrane (Cascade, MTF, Edison NJ) secured using absorbable suture (right knee flexed 90° viewed through an arthroscopic central portal). © F. Alan Barber, M.D.

positioned within the femoral tunnel. The graft was tensioned with the knee in 20° to 30° of flexion.

All allografts were provided by the same supplier (Musculoskeletal Tissue Foundation [MTF], Edison, NJ) and were neither irradiated nor chemically processed. Only allografts with a tendon segment length of less than 40 mm were used to avoid issues with graft-tunnel mismatch. The tendon portion of the allografts was wrapped with platelet-rich fibrin membrane, which was secured using absorbable suture (Fig 3). Autografts with long tendon segments sometimes presented a problem. In order to deal with a graft-tunnel mismatch, 2 different techniques were employed. For autografts with a tendon length between 40 and 50 mm, the distal bone plug was rotated one to one and one-half full turns after securing the proximal femoral plug. This shortened the tendon length by up to 1 cm and increased the graft stiffness. Autografts with a tendon length greater than 50 mm were addressed using the FLIP technique. In the FLIP technique, the tibial bone segment is reduced to a 2-cm length and flipped back over the adjacent patellar tendon so that the cancellous portion faces away from the tendon. This shortens the tendon portion to 3 cm or slightly less. This provides adequate bone to achieve good interference fixation between the cancellous surface of the bone plug and the cancellous bone of the tunnel wall. This technique is not possible for allografts because the tendon will strip away from the bone plug if reversed in this manner.

The postoperative rehabilitation was dependent on the type of graft used. Autograft patients were initially allowed full range of motion while wearing a brace locked in full extension only at night and using a continuous passive motion machine for 6 to 8 hours per day. Physical therapy was initiated in the preoperative period and continued starting in the first week postoperatively. If full extension was achieved, night-time bracing was discontinued after 2 weeks. At 8 weeks, the patients could begin straight-ahead, half-speed jogging. At 12 weeks, noncontact pivoting activities were allowed. Once the measured thigh circumference was within 2 cm of the nonoperative contralateral side (usually between 12 and 16 weeks), the patient was fitted for a derotational knee brace. After 16 weeks, full-contact pivoting sports were allowed while wearing the derotational brace. Patients were asked to continue to wear this knee brace during pivoting sports for the first year postoperatively.

Knowing that allograft reconstruction patients would have less knee pain but a slower graft incorporation time, the allograft patients were placed in a hinged knee brace and knee motion slowly advanced from 0° to 30° postoperatively to full motion starting at 6 weeks after surgery. Prone hangs and bridging stretches were emphasized to achieve and maintain full extension. Biking was allowed starting at 8 weeks, half-speed jogging (no pivoting) at 12 weeks, and noncontact pivoting at 5 months after surgery. A derotational brace was fitted if quadriceps circumference was within 2 cm of the contralateral side between 5 and 6 months after surgery. At 6 months, the patients were allowed to begin full-contact pivoting sports wearing the derotational brace. The patients were asked to continue using the brace for any pivoting sports until 2 years after surgery.

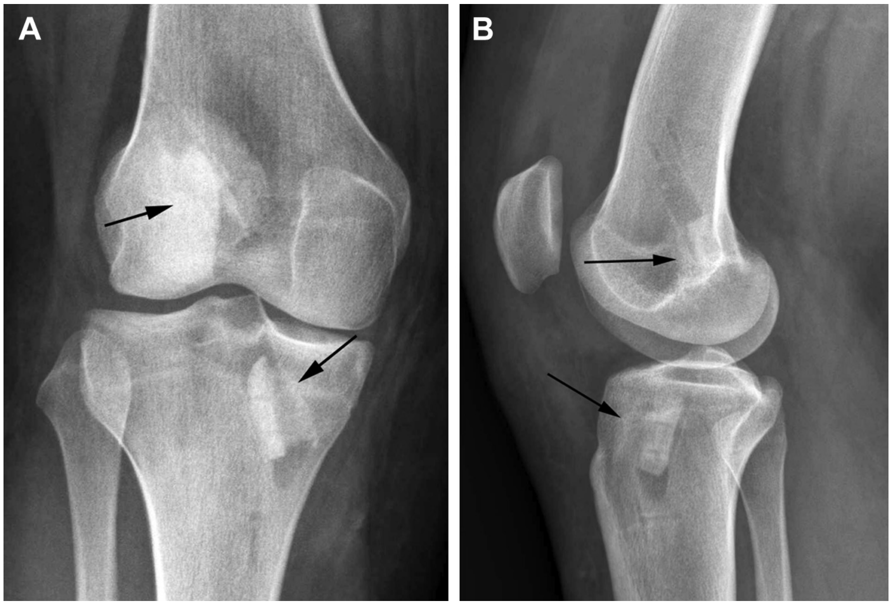

Fig 4. The biocomposite screw facilitated postoperative radiographic assessment of the graft placement. (A) Anteroposterior and (B) lateral views of the right knee taken 1 week after surgery. The Milagro interference screw (arrow) is seen adjacent to the BPTB plug. © F. Alan Barber, M.D.

All repaired meniscus tears were longitudinal peripheral tears with no degenerative changes in the red-red or red-white zone. A meniscus repair did not alter the ACL rehabilitation protocol. The accelerated rehabilitation program has been shown to have no influence on meniscus repair outcomes.[17-20]

Preoperative and postoperative assessments, including a history, physical examination, radiographs, Cincinnati, Lysholm, and International Knee Documentation Committee (IKDC) activity scores, were obtained in all patients. In addition, postoperative assessments included a Tegner knee score, and KT arthrometer (Medmetric Corp, San Diego, CA) measurements were obtained. The final follow-up physical examination was performed and documented by a nonblinded examiner who was not the surgeon to reduce observer bias. Surgical failures were defined as a subsequent ACL revision surgery, a 2+ Lachman test, a positive pivot-shift, or a side-to-side KT difference of greater than 5 mm.

The primary outcome measure was failure or the need for revision ACL reconstruction, or both. Secondary outcome measures were the clinical outcome scores.

Statistical Analysis

The patient demographic data, including age, sex, side of injury, and history of previous ACL surgery, was summarized and compared using the Student *t* test. Preoperative and postoperative functional scores as well as physical examination findings, such as range of motion, Lachman scores, and KT scores, were also compared using the Student *t* test. Associated findings noted during surgery, including areas of chondral damage and meniscal tears, were recorded and averaged. Using published literature,[2] which demonstrated a nearly 30% difference in the revision rate between allografts and autografts within 2 years of the index procedure, a power analysis determined that 81 patients represented sufficient sample size to determine clinical significance assuming a beta of 0.2. A Kaplan-Meier survivorship analysis was performed comparing the 2 graft groups. All data analysis was performed using Epi Info 7 (Centers for Disease Control, Atlanta, GA).

Results

During the study period (from 2001 through 2012), 603 ACL reconstructions were performed by the senior author (F.A.B.). Of these, 81 ACL reconstructions were performed on patients 25 years old or younger and met the other inclusion criteria and were available for reevaluation at least 24 months after surgery. These included 28 BPTB allograft patients and 53 BPTB autograft patients. All grafts were secured using biocomposite Milagro interference screws, which facilitated postoperative radiographic assessment of the graft placement (Fig 4). The Milagro biocomposite screw is made from poly L-lactide-co-glycolide and beta-tricalcium phosphate, and this material has demonstrated significant osteoconductivity without any lysis at the screw site.[21,22] In fact, 50% of the screw sites demonstrated significant or complete osseous replacement.[22]

The mean follow-up for all included patients was 34 months. The mean allograft follow up was 37 months (range, 24-71 months) and the mean autograft follow-up was 31 months (range, 24-132 months). The overall mean age was 19.1 years (allograft group: 20.1 years; range, 14-25 years) (autograft group: 18.6 years; range, 13-25 years) ($P = .04$). The allograft group had 14 male

Table 1. Associated Lesions Found at the Time of ACL Reconstruction

Associated Lesions	Allograft (n = 28)	Autograft (n = 53)
Chondral damage	6 (21%)	11 (21%)
Medial femoral Condyle	0	1
Trochlea	0	2
Patella	5	8
Lateral tibial plateau	1	0
Meniscal tears	19 (68%)	38 (72%)
Lateral (repaired)	10 (5)	23 (9)
Medial (repaired)	13 (10)	25 (17)

patients and 14 female patients, whereas the autograft group had 26 male patients and 27 female patients ($P = .94$). The allograft group included 14 right and 14 left knees, whereas the autograft group included 21 left and 32 right knees ($P = .38$).

Associated pathology found during the ACL reconstruction procedure is noted in Table 1. No lytic changes or bone reabsorption was found associated with the Milagro screws.

Our primary outcome measure was ACL reconstruction failure. There were 7 failures identified in these 2 groups: 2 of 28 (7.1%) among the allografts and 5 of 53 (9.4%) among the autografts. Table 2 outlines each of these patients and their mechanisms of reinjury. A Kaplan-Meier survivorship analysis (Fig 5) was performed between the 2 groups and no significant difference was obtained ($P = .85$).

The average KT difference between knees in the allograft group was 0.59 mm (SD = 1.5) and 0.34 mm in the autograft group (SD = 1.9); this difference was not significant ($P = .58$). Of the KT values obtained, the allograft patient group had 22 patients with KT values less than 3 mm, 3 patients between 3 and 5 mm, and no patients greater than 5 mm. The autograft patient group had 43 patients with KT values less than 3 mm, 6 patients between 3 and 5 mm, and 1 patient greater than 5 mm.

At final follow up, the allograft and autograft groups had 3 patients each with a grade 1+ Lachman examination and no patients with any higher grade examinations. Average flexion at final follow-up for the allograft group was 135° and 136° for the autograft group ($P = .74$).

The mean preoperative Cincinnati scores improved from 54.6 and 39.5 (allografts and autografts, respectively) to 86.2 and 85.1 postoperatively. Mean Lysholm scores improved from 60.3 and 44.8 (allografts and autografts, respectively) to 89.9 and 87.0. This was a significant improvement for both Cincinnati scores ($P < .01$) and Lysholm scores ($P = .014$). However, the Cincinnati ($P = .02$) and Lysholm ($P = .026$) preoperative scores were lower in the autograft group than in the allograft group. IKDC activity scores (on a scale of 4) were 1.9 and 3.3 (allografts and autografts, respectively) preoperatively and 2.9 and 3.1 postoperatively. The IKDC scores were not significantly different ($P = .32$). No significant difference was found between autograft and allograft groups for the Cincinnati ($P = .76$), Lysholm ($P = .43$), and final IKDC ($P = .3$) scores.

Discussion

Graft options for ACL reconstruction include both autografts and allografts. Some have suggested that allograft tissue in the young results in higher failure rates.[9,12,23-25] Others have argued that there is no difference in failure rates for young patients with allograft ACL reconstructions.[10,14,26]

The primary outcome measure of this study was graft failure. The Kaplan-Meier survivorship analysis failed to demonstrate a significant difference between the 2 groups for this primary outcome measure. There was also no significant difference for the secondary outcomes measures, including the Cincinnati, Tegner, Lysholm, and IKDC scores. The lack of a significant difference in postoperative physical examination findings, including KT measurement, Lachman examination, and range of motion, reinforces the conclusion that postoperative outcomes between these 2 groups of allograft and autograft BPTB reconstructions were similar.

Other authors have studied ACL reconstruction in young patients. Recently, Ellis et al.[2] followed 79 ACL reconstructions with allografts and autografts in patients 18 years and younger with closed physes and demonstrated no significant difference between groups in function, activity, or satisfaction. Their allograft group was reported to be 15 times more likely to require a revision than their autograft group. Significantly, all allograft failures occurred within 1 year of surgery. However, this study used 2 separate sources of allograft tissue: RTI Biologics (Alachua, FL) and

Table 2. Patient Demographics and Mechanism of Reinjury in Failures

Patient	Sex	Age (yr)	Side of Injury	Graft Type	Time to Failure (months)	Mechanism of Failure
1	Male	18	Left	Autograft	8	Motorcycle collision
2	Female	18	Right	Autograft	56	Flag football injury, contact
3	Female	19	Left	Autograft	19	Basketball injury, noncontact
4	Female	16	Left	Autograft	62	Unknown
5	Female	15	Left	Autograft	44	Soccer injury, noncontact
6	Male	24	Left	Allograft	13	Fell jumping off a box, noncontact
7	Male	23	Left	Allograft	2	Fall

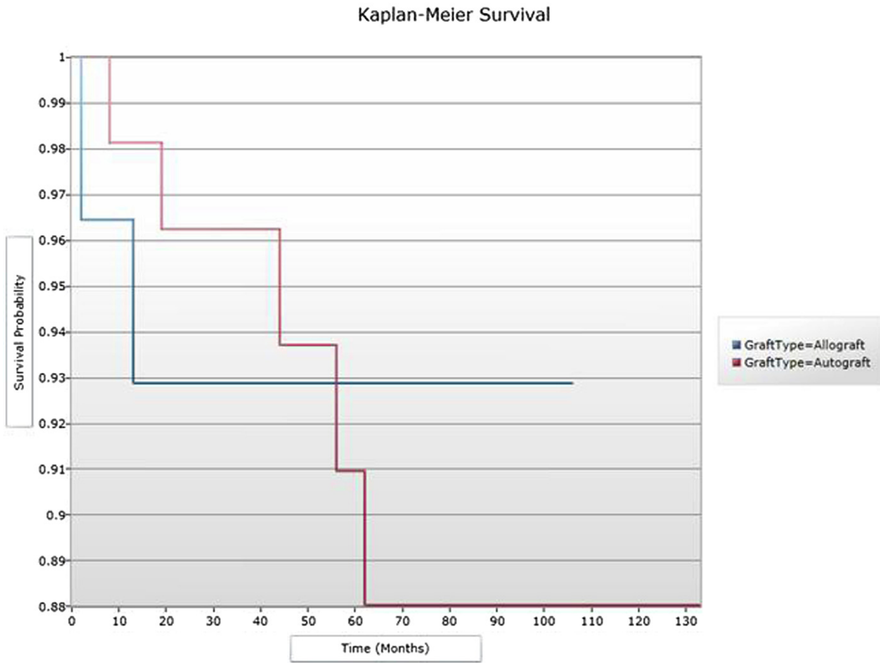

Fig 5. Kaplan-Meier survivorship curves. Allografts are shown in blue and autografts are shown in red. © F. Alan Barber, M.D.

AlloSource (Centennial, CO). Three of the 7 allografts that failed were treated using a proprietary chemical method and the other 4 were treated with "low-dose radiation." Both processing techniques may have influenced the allograft failure rate, and neither processing technique is used with the MTF allograft tissue employed in this study.

Sun et al.[14] reported 99 prospectively randomized BPTB allograft and autograft patients divided into 3 groups (autograft, 33; nonirradiated allograft, 34; and irradiated allograft, 32). They found 88% of the autograft group and 85% of the nonirradiated allograft group, but only 31% of the irradiated allografts, had KT side-to-side differences less than 3 mm. More importantly, the failure rate of the irradiated allografts (34.4%) was higher than that of the autografts (6.1%) and the nonirradiated allografts (8.8%), with no significant difference between the nonirradiated allograft group and the autograft group. This underscores the importance of understanding what types of graft are being compared and an appreciation that the graft source is significant.

Although none of our patients was older than 25 years of age, the patients choosing a BPTB autograft were younger (18.6 years) than those choosing the BPTB allografts (20.1 years) ($P = .04$). This difference is consistent with younger high school athletes still living in a family setting more interested in a rapid return to sports compared with older patients out on their own and responsible for their own insurance who may be more interested in an earlier return to university studies, a desk job, and less pain.

Allograft tissue is known to have a slower incorporation time in animal models, compared with autografts.[27,28] This slower incorporation has been confirmed in human studies as well[29] and has led some authors to recommend a delayed return to sports or full activities in allograft patients.[11] Indeed, these allograft patients were treated with significantly slower returns to various activity milestones compared to the autograft patients. This included the return to straight-ahead jogging, noncontact pivoting, and full-contact pivoting sports.

One factor seldom addressed in other studies is the nature of the allograft material used. This cannot be overemphasized. All allografts used in this study came from a single source: MTF, for which the American Association of Tissue Banks guidelines are minimum criteria for acceptance, and in fact the MTF selection criteria exceed these standards. MTF's graft processing avoids damaging radiation on the final tissue form of the graft or the use of harsh chemicals like hydrogen peroxide, which may decrease osteoconductivity.[30]

Gamma irradiation affects graft strength[5,31] and has been shown to result in higher failure rates.[14,15,32] Any study examining the differences between autograft and allograft ACL reconstruction must include information about the recovery and processing of the allografts. Different allograft studies cannot be assumed to be equivalent unless these critical differences in allograft processing are noted.

In a meta-analysis of 256 patients with a minimum 2-year follow-up, BPTB allografts were found to have an increased failure rate compared with BPTB autografts. However, if irradiated allografts were excluded, all differences between the allografts and autografts disappeared. Mehta et al.[23] demonstrated a significant difference in revision rates between 142 BPTB autografts (0.7%) and 31 allografts (9.7%). Forty-five percent of the allografts used were irradiated. All failures occurred in the irradiated allografts. If the irradiated allografts were excluded from the study, no statistical difference remained between the autograft and allograft groups.

The type of allograft is also a significant factor. Allograft ACL reconstruction outcome reports have used hamstring[15,33,34] and BPTB allografts without reporting the type of processing used,[12,35] looked at all types of allografts,[7,25] or lumped all allografts together and failed to report the type of allograft used.[36-38] It cannot be assumed that all allografts are equivalent. Reports have shown BPTB autografts provide better stability compared with soft tissue autografts.[9,39,40] Different types of allografts with different processing can reasonably be expected to have different outcomes as well.

Our BPTB allografts are not necessarily equivalent to our BPTB autografts. There is a selection bias to consider as well as the underlying reasons for this selection. Once the patients were informed about the differences between the 2 grafts (pain, incision size, cosmesis), the surgical procedure, and the postoperative protocol, those principally interested in a quicker return to high-performance pivoting athletics selected the autograft. Others selected the allograft BPTB. This could be because of less postoperative pain, the absence of an incision, the shorter time away from school or work, or the decreased out-of-pocket costs. In our patient population, with the current insurance copayment system, patients must make a copayment that can be as much as $50 with every physical therapy visit. Many have only a limited number of physical therapy visits allowed. A BPTB autograft rehabilitation may require as many as 30 physical therapy visits to achieve the desired milestones of full extension, good flexion, and adequate strength. An allograft's rehabilitation usually requires far fewer. It became apparent that many patients considered their own out-of-pocket costs in making this decision.

Although patient age has been emphasized as a limiting factor for allograft selection, the real cause may be activity levels and patient compliance. Higher activity levels are commonly found in younger age groups. In a case-control study, univariate logistic regression models showed increased odds of ACL graft failure for those with high activity levels compared with low activity levels. Additionally, these authors report higher failure rates for allografts compared with autografts. However, BPTB allografts were not used, and the soft tissue allografts in this study were irradiated.[24]

Finally, underscoring the activity issue, 78 patients younger than the age of 40 years were evaluated after a BPTB nonirradiated allograft ACL reconstruction and compared with 411 BPTB autograft patients. High-activity allograft patients were found to have a 2.6- to 4.2-fold increase in the probability of graft failure compared with low-activity allograft patients and low- and high-activity autograft patients.[11]

The cause of ACL reconstruction failure in younger patients is a complex issue. Just looking at age and a generic "allograft" is being overly simplistic. All allografts are not the same. Soft tissue grafts are distinctly different from BPTB grafts. Graft processing is a significant variable, and chemical processing or irradiation will weaken the allograft tissue. Finally, different rehabilitation programs are required for allograft tissue, which takes significantly longer to incorporate into the site and remodel than autograft tissue.

Limitations

Study weakness included the relatively short 2-year follow-up time. However, allograft failures have been noted to occur usually within 2 years of surgery.[2] Therefore, most allograft group failures should have occurred during the study period. Selection bias exists. However, this was inherent to the informed consent process and allowing patients and parents autonomy in the choice of surgery. Varied patient activity levels placed different stresses on the 2 groups. Also, expectations play a large role in the patient's graft choice, which has been shown to be an independent risk factor for failure in this age group.[11] Finally, this study looked at reoperation rates and not reinjury rates.

Conclusions

Using a patient-choice ACL graft selection program after appropriate counseling and using graft-specific rehabilitation programs, not chemically processed or irradiated BPTB allograft reconstructions have no greater failure rate than autografts in patients aged 25 years and younger at a minimum 2-year follow-up. No significant differences in Cincinnati, Lysholm, and IKDC activity scores were found between these 2 groups.

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