Use of Allografts in Knee Reconstruction: II. Surgical Considerations

Walter R. Shelton, MD, Stephen H. Treacy, MD, Andrea D. Dukes, MS, and Anna Laura Bomboy, BS

Abstract

The first allograft used in the knee was articular cartilage. The need to use fresh grafts and the absence of proper instruments for shaping and sizing implants have prevented widespread usage of articular cartilage allografts. Patient selection is very important; young, active, well-motivated individuals with defects smaller than 4 cm² caused by trauma or osteochondritis dissecans have the best results. Failure is evidenced by crumbling of the supporting bone and fragmentation of the graft, a process identical to that seen in osteonecrosis. The use of allografts to reconstruct knee ligaments has gained wider acceptance. The availability of high-quality tissue from modern tissue banks, excellent preservation methods, a decrease in short-term surgical morbidity, and results at 2- to 5-year follow-up that are essentially equivalent to those obtained with autogenous grafts have combined to make allografts an alternative to using the patient's own tissue. However, long-term stability results are needed for comparison with autogenous grafts. Replacing an unsalvageable meniscus with an allograft is an appealing concept, with the potential for restoring normal load distribution, lubrication, and stability in the knee. Healing of the grafts and pain reduction have been reported by several investigators, but concerns about graft shrinkage, central hypocellularity, and long-term functional survival remain.

J Am Acad Orthop Surg 1998;6:169-175

The loss of hyaline articular cartilage is disabling and usually leads to degenerative arthritis of the knee. Many surgical procedures have been used to overcome this loss of cartilage, including fat interposition, tibial and femoral osteotomies, abrasion chondroplasty, drilling, microfracture, and total joint replacement. Attempts to repair a defect by abrasion, microfracture, or drilling result in production of a fibrocartilage repair, which is inferior to hyaline articular cartilage in weight-bearing and wear characteristics. More recently, autogenous articular-plug grafting and free chondrocyte implantation have gained considerable attention. These techniques are new, and long-term follow-up will be necessary to assess their efficacy.

Articular Cartilage Allografts

Use of allograft articular cartilage to resurface a defect in the knee is a seldom used but proven alternative. Despite the requirement that all allografts must come from fresh specimens, investigation into hyaline articular cartilage transplantation continues. The advantages of no donor-site morbidity and a relatively inexpensive graft source are important considerations.

History

In 1925, Lexer[1] was the first to report the transplantation of articular cartilage. He reported a 50% success rate in 23 cases involving the knees, fingers, and elbows. Reports of articular cartilage allografts were absent from the literature until the 1960s. Their reemergence coincided with increased understanding of organ transplantation and the role of the immune system.

Indications

Patient selection is critical for a successful articular cartilage allo-

Dr. Shelton is in private practice with Mississippi Sports Medicine & Orthopaedic Center, Jackson, Miss. Dr. Treacy is in private practice with Rezin Orthopaedic Center, Morris, Ill. Ms. Dukes is a medical student, University of Mississippi School of Medicine, Jackson. Ms. Bomboy is Clinical Research Assistant, Mississippi Sports Medicine & Orthopaedic Center.

Reprint requests: Dr. Shelton, Mississippi Sports Medicine & Orthopaedic Center, 1325 East Fortification Street, Jackson, MS 39202.

graft. Currently there are two indications for their use: (1) an articular defect caused by trauma and (2) an articular defect caused by osteochondritis dissecans. Use of allografts in patients with rheumatoid arthritis, generalized osteoarthritis involving both sides of the joint, and corticosteroid-induced osteonecrosis has universally met with failure and is not recommended.

Patients being considered for an articular cartilage allograft should be active and well motivated. Any limb malalignment must be corrected before transplantation. Most articular-cartilage allografting procedures have involved resurfacing defects of the femoral condyles, but defects involving the tibial plateau, patella, trochlea of the humerus, elbow, and talus have also been grafted successfully.

Surgical Considerations

Transplantation of articular cartilage requires implantation of an underlying portion of bone both for support and as a means of rigid internal fixation. Failure of articular cartilage allografts is usually preceded by collapse of the underlying bone with fragmentation of both the bone and the articular cartilage, similar to the process seen in osteonecrosis. This process may be due, at least in part, to a subclinical immune response that is undetectable. However, early attempts failed as a result of resorption and collapse of the osseous platform.

Recently, tissue matching and the use of immunosuppressant drugs have gained attention in the transplantation of articular-cartilage allografts. Lipson et al[2] reported that grafts transplanted in tissue-matched rats appeared normal at 6 months, and Gotfried et al[3] demonstrated an immune rejection reaction with articular-cartilage allografts in tissue-mismatched animals. Stevenson et al[4] had superior results with massive fresh articular-cartilage allografts that were tissue-matched. They demonstrated viable articular cartilage, although it was somewhat thinner and duller than normal cartilage. Their frozen mismatched grafts had the appearance of fragmentation and degeneration, similar to that seen in degenerative arthritis.

Czitrom et al[5] obtained biopsy specimens of human articular-cartilage allografts 12 and 72 months postoperatively and found that all had viable, functionally and metabolically active chondrocytes. Oakeshott et al[6] reported that 12 failures in a series of 108 articular-cartilage transplantations appeared to have fragmentation of the underlying bone and changes of osteoarthritis.

Procurement of articular-cartilage allografts is a challenge. Articular-cartilage matrix is damaged by preservation with freezing with or without cryopreservation; therefore, the most widely used method of transplantation is the use of a fresh graft. Most grafts have been implanted within 24 hours of death of the donor, and problems with sizing and timing have been noted.

The surgical procedure requires an arthrotomy for directly visualizing and removing any fibrous tissue from the defect. The best results are obtained with lesions measuring 4 cm^2 or less, although there are reports of successful resurfacing of larger defects. However, the efficacy of transplantation for these smaller defects has not been directly compared with that of other techniques. The graft should be shaped and fitted for rigid internal fixation.

Postoperatively, motion is begun immediately. Weight bearing is delayed at least 8 weeks, depending on the size of the graft.

Results

The largest reported series of articular-cartilage allografts is that of Zukor et al,[7] from the University of Toronto. Their series began in 1972, which coincided with the establishment of their tissue bank. In 100 cases, the best clinical results were seen with traumatic unipolar grafts. Success was also reported with osteochondritis dissecans but was less predictable. Of the 59 allografts with more than 1-year follow-up (55 in the knee, 2 in the talus, 1 in the humeral capitellum, and 1 in the finger), 45 (76%) were successful. The graft failed in all four patients in whom both sides of the joint were grafted. At 5 years, the success rate in 92 knees was 75%; at 10 years, 64%; at 14 years, 63%.

Garrett[8] reported an 85% success rate for allograft reconstruction of 2- to 4-cm^2 knee defects due to osteochondritis dissecans. At second-look arthroscopy, successfully treated knees demonstrated normal-appearing articular cartilage. Failed grafts were characterized by failure of incorporation of the underlying bone and fragmentation of the graft.

Mankin et al[9] reported success with partial survival of articular cartilage after the use of massive allografts in tumor reconstruction. In that study, cryopreserved tissue, rather than fresh cartilage, was used.

Summary

The ultimate success of an articular-cartilage allograft depends on the survival of the articular matrix with its chondrocytes and the union of underlying bone. Normal function of chondrocytes is mandatory if the cartilage is to survive. The best results are obtained in young persons with a defect measuring less than 4 cm^2 that affects only one side of the joint, preferably the femoral condyle.

Osteochondral fractures and osteochondritis dissecans are the only surgical indications at present. The use of tissue matching and immunosuppression may improve future results.

The need for fresh grafts is a major reason why few surgeons have used articular-cartilage allografts. The lack of special instruments for graft sizing and shaping is also a problem. Whether renewed interest is shown in articular-cartilage allografts and whether this concept will be bypassed by newer ones, such as free chondrocyte implantation and plug autografting, remain to be seen.

Ligament Allografts

History

The importance of knee stability to the long-term function of the knee has been well established. Chronic knee instability is associated with an increased frequency of meniscal tears and the development of osteoarthritis over time. The immediate effects of an unstable knee can often prevent an athlete from returning to sports.

Treatment options include rehabilitative exercises, bracing, and surgical reconstruction. Braces are usually an important addition to the overall treatment, but few patients can resume normal running and cutting movements with bracing and exercise alone. Surgical reconstruction is most often required, especially for young, active patients.

The search for the ideal graft source for knee ligament reconstruction has included autografts, allografts, xenografts, and synthetics. Autografts and allografts offer several tissue choices, including patellar tendon, quadriceps tendon, fascia lata, hamstring tendon, and Achilles tendon. Allografts have the obvious advantage of decreasing surgical donor-site morbidity and can be used in revision cases when no suitable autogenous tissue is available.

Indications

The decision to use a knee-ligament allograft depends on several factors, including patient and surgeon preference, the particular ligament being reconstructed, the availability of suitable autogenous tissue, and the availability of a safe, high-quality source of allografts. The surgical techniques and methods of fixation for allografts are identical to those for autografts. Postoperative morbidity with allografts is less, due in large part to the fact that no donor tissue is harvested. Rehabilitation with rapid institution of range-of-motion and other exercises is generally applicable to allografts, as it is with autogenous tissue.

Although a variety of allograft tissues are available for use, the tissue most commonly used for anterior cruciate ligament (ACL) reconstruction is the bone–patellar tendon–bone composite. While some advocate allograft patellar tendon for primary ACL reconstruction, most surgeons prefer autogenous tissue and rely on patellar tendon allograft reconstruction for revision procedures. An Achilles tendon allograft is commonly used for the reconstruction of the posterior cruciate ligament because of its size, strength, length, and ease of insertion. Other structures that have been reconstructed with an allograft include the medial collateral ligament, the patellar tendon, the lateral collateral ligament, and the posterior capsule. However, due to the limited number of cases, insufficient evaluable data are available to reach conclusions regarding graft choices and indications for these areas.

Surgical Considerations

Once the remodeling phase is complete, implanted allograft ligament tissue appears similar to the native ACL. Shino et al[10] demonstrated that by 52 weeks after surgery, bone–patellar tendon–bone allografts implanted in dogs had regained a fibrous framework histologically similar to that seen in a normal ligament. Arnoczky et al[11] found that after 1 year dog patellar tendon allografts resembled normal ACLs both grossly and histologically. In their study in a goat model, Drez et al[12] found that bone–patellar tendon–bone allografts histologically resembled normal ACL tissue after 26 weeks. Also using a goat model, Jackson et al[13] demonstrated a similar connective tissue pattern in native and allograft ACLs, as well as periligamentous and endoligamentous vascular patterns consistent with a normal ACL. Second-look arthroscopy findings reported by Shino et al[14] illustrated that ACL allografts had reached histologic maturity by 18 months postoperatively. Cordrey et al[15] observed that while vascularization and recollagenization occur in autograft and allograft ligaments in a similar fashion, those processes occur more slowly in allograft tissue.

The histologic and vascular characteristics of ligament allografts are well established; however, their tensile strengths vary widely. Thomas and Gresham[16] demonstrated that freeze-dried fascia lata grafts are initially equal in strength to fresh allograft tissue. During incorporation, ligament grafts are weakest during the phases of revascularization and maturation, with maximum weakness occurring 6 months after implantation. Drez et al[12] found that allograft ACLs had a maximum load to failure of 43% of normal at 26 weeks postoperatively. Jackson et al[13] showed a maximum load to failure of 27% of normal for allograft ACLs, compared with

62% of normal for autografts. In contrast, Nikolaou et al[17] demonstrated 90% normal strength in cryopreserved dog allograft ACLs at 36 weeks. Despite the fact that ligament allografts are weaker during incorporation, there are no published reports citing increased likelihood of failure during this phase.

With this variability in results, no clear-cut conclusion can be reached regarding the maximum load to failure of allograft ligaments in an animal model. Despite the variation in tensile strength data, the encouraging early clinical results reported by Noyes and Barber[18] and by Shino et al[14] have led to the acceptability of allograft tissue in reconstructing knee ligaments. The advantages are smaller incisions, less surgical time, and potentially less surgical morbidity.

Results

Most of the data collected on allografts deal with reconstruction of the ACL with bone–patellar tendon–bone grafts. Shino et al,[19] using Achilles tendons or multiple-strand peroneal tendons to treat 84 patients, reported good to excellent results in 94% at follow-up examinations 3 years or more after surgery; on arthrometric measurement, 84% had side-to-side differences of 3 mm or less. Indelicato et al[20] reviewed fresh-frozen bone–patellar tendon–bone allografts with an average 27-month follow-up; their objective results were similar to their experience with autograft patellar tendons, with 93% of patients having Lachman scores of grade I or less and 78% having a completely negative pivot-shift examination. Shelton et al[21] found no statistical difference between autograft and allograft bone–patellar tendon–bone ACL reconstructions in terms of pain, effusion, stability, range of motion, patellofemoral crepitus, and thigh circumference when evaluated a minimum of 24 months after surgery. Harner et al[22] found similar results when comparing allograft and autograft ACL reconstructions at 3- to 5-year follow-up. Noyes et al[23] compared bone–patellar tendon–bone allografts with fascia lata allografts with a 2-year follow-up and reported 89% good to excellent results in both groups; however, they found better arthrometric stability results with bone–patellar tendon–bone grafts.

Overall, the results of primary reconstruction with use of allografts are similar to those obtained with autografts. Some concern has been expressed that allografts might begin to show increased laxity or re-rupture rates 5 years or more after surgery, but no series with data showing evidence of these possibilities has been published. Allografts are often reserved for use in revision ACL reconstructions, but revision surgeries have proved less successful than primary reconstructions.

Studies showing the results of allograft use in posterior cruciate ligament reconstruction are not as numerous as those dealing with the ACL. Noyes and Barber-Westin[24] demonstrated good restoration of posterior stability with either bone–patellar tendon–bone or Achilles tendon allografts and found no benefit with synthetic augmentation. Bullis and Paulos[25] reported on 63 patients, many with combined injuries, and demonstrated good results with the use of Achilles allografts, but with only a 12-month follow-up. Noyes and Barber-Westin[26] reported the results in 20 patients with posterior lateral instability who were treated with Achilles tendon, fascia lata, and bone–patellar tendon–bone allografts; at the follow-up evaluation a mean of 42 months after surgery, the success rate was 76%.

Summary

The use of allograft tissue as a graft source for reconstruction of knee instabilities is an alternative for ligament reconstruction. Many factors enter into the decision to use an allograft, including patient age, the preference of the patient and the surgeon, fear of disease transmission, and availability of quality tissue. Both the surgeon and the patient must be aware that although the graft will react much like autogenous tissue in revascularization and remodeling, this process tends to progress more slowly. Long-term studies with a minimum 5-year follow-up are lacking, and there is the possibility that allografts will be found to have stretched when checked at longer intervals.

Meniscal Allografts

History

The meniscus was long thought to be a rudimentary appendage with no function or purpose. Surgical concepts were developed that advocated total meniscectomy for any suspected or established pathologic condition. Removal of the meniscus was proposed to enhance ligament stabilization by allowing the creation of an extra tuck when tightening the posterior medial capsule. The regenerated meniscus after total meniscectomy was noted to be a perfect replica of the original, although smaller. Unfortunately, this regenerated meniscal tissue does not functionally distribute the stress of weight bearing or prevent postmeniscectomy degenerative arthritis.

Attitudes about the importance of the meniscus began to change after Fairbank's 1948 article[27] showed that the late radiographic findings after meniscectomy represent degenerative arthritis. As a

greater awareness of the importance of the meniscus has evolved over the past 30 years, strategies for meniscal salvage by partial meniscectomy and meniscal repair have been developed.

The problem of the unsalvageable meniscus remained, leading to the concept of meniscal replacement with an allograft. Arnoczky et al[28] proved the feasibility of transplanting an allograft meniscus by demonstrating peripheral healing, cellular repopulation, and the lack of an immune response in a dog model.

Indications

The ideal candidate for a meniscal allograft is a young, active individual with pain over a previously meniscectomized compartment. The general consensus at recent Meniscal Allograft Study Group meetings is that the best results are obtained in knees with little or no arthritic damage. Standing radiographs should demonstrate acceptable limb alignment, and any malalignment should be corrected before considering a meniscal replacement.

Instability should be corrected before or during meniscal replacement because abnormal forces applied to a meniscus placed in an unstable joint will likely lead to failure. The combination of a meniscal allograft and ligament reconstruction should have a synergistic effect by enhancing stability and restoring more normal knee kinematics.

The expense of a meniscal allograft must be considered. The cost of the graft itself can range from $2,500 to $3,500; when that is added to surgical, anesthesia, and facility fees, the total bill may exceed $15,000. Many third-party insurers have resisted approving the allografts, citing the investigational nature of the procedure. Long-term outcome studies documenting a reasonable cost-benefit ratio will be required to improve reimbursement.

Surgical Considerations

Preoperative planning is important to ensure proper sizing of the meniscal allograft. Plain radiographs are sent to the tissue bank, and after allowing for magnification, a properly sized graft is selected. It is kept frozen on dry ice until immediately before transplantation.

Early meniscal allografts were implanted with an open technique, often with collateral ligament release. Anatomic placement and peripheral suturing were straightforward with this exposure, but operative morbidity was considerable. Arthroscopic implantation techniques evolved rapidly, lowering morbidity and cost but increasing technical demands.[29] Meniscal allografts are now done as outpatient procedures with arthroscopically assisted methods.

The anchoring of both meniscal horns with either bone plugs or slots was added to overcome peripheral extrusion of the graft with weight bearing. Peripheral suturing of the graft completes the procedure, and rehabilitation is similar to that used after meniscal repair.

Results

Most of the menisci that have been implanted as allografts were provided by CryoLife, Inc (Kennesaw, Ga). A total of 1,080 CryoLife cryopreserved menisci (784 medial, 296 lateral) were implanted between 1989 and 1996 by 165 surgeons. The data collected on 720 of these grafts with a minimum 8-month follow-up showed that 94% medial and 93% lateral survival rates were obtained when bone anchors were used. Recent papers suggest that relief of pain has been the most consistent clinical benefit. Results at 2- to 5-year follow-up show pain relief in more than 90% of allograft recipients.

Decreased range of motion, increased swelling, and clinical rejection have not been problems in any series. Shrinkage of the graft has been noted but is difficult to measure; the incidence has been estimated as 10% to 15% on second-look arthroscopy but 30% on magnetic resonance (MR) imaging studies. Certainly, any shrinkage would decrease the ability of the meniscus to distribute weight over a large surface area and thereby render it less functional. Biopsy specimens have demonstrated peripheral healing and surface hypercellularity but central hypocellularity.

At the 1995 meeting of the Meniscal Allograft Study Group, Noyes reported poor results with the use of irradiated grafts in a series of 96 meniscal allografts. In that series, 66% of the recipients had arthritic knees, and 78% of the menisci failed or healed only partially. Only 12% of failures were seen by 6 months. He has emphasized caution when evaluating meniscal allograft studies with a follow-up period of less than 2 years and no MR imaging or arthroscopic second-look data.

Our results in 17 patients followed up for an average of 40 months (range, 13 to 64 months) showed improvements in Lysholm and Tegner scores and excellent subjective pain relief in 15 of the 17. The MR imaging studies of 9 of the patients showed no peripheral extrusions of the allograft meniscus but only 71% of the volume of the normal meniscus in the opposite knee. The loss of meniscal volume is a problem because the function of load distribution, and thus protection of the articular cartilage, is

compromised by any loss of meniscus size.

Summary

Currently, the only indication for a meniscal allograft is the presence of persistent pain in a meniscectomized compartment in a young patient with minimal or no arthritic change in the knee. The technical aspects of the procedure are very demanding; therefore, it should be performed only after considerable practice.

The short-term reports of pain relief in most recipients are encouraging; however, one must always bear in mind that pain relief is subjective and the possibility of some placebo effect must be considered. Long-term studies documenting the preservation or degradation of the articular cartilage and the survival of the allograft meniscus are necessary before transplantation of a meniscal allograft can be considered a good solution to the problem of the unsalvageable meniscus. The problem that must be investigated next is the prevention of graft shrinkage and central hypocellularity.

Conclusion

The use of an allograft has become a useful option when planning knee reconstructions. Advances in immunology and prevention of disease transmission should enhance future results. Long-term results with more than 5 years of follow-up are needed to assess the durability of these replacement grafts. The ultimate goal should be a graft that adequately replaces the damaged ligament, cartilage, or meniscal surface; heals in a high percentage of patients; and functions well over a long period of time.

References

1. Lexer E: Joint transplantations and arthroplasty. *Surg Gynecol Obstet* 1925;40:782-809.
2. Lipson RA, Kawano H, Halloran PF, Pritzker KP, Kandel R, Langer F: Vascularized limb transplantation in the rat: II. Results with allogeneic grafts. *Transplantation* 1983;35: 300-304.
3. Gotfried Y, Yaremchuk MJ, Randolph MA, Weiland AJ: Histological characteristics of acute rejection in vascularized allografts of bone. *J Bone Joint Surg Am* 1987;69:410-425.
4. Stevenson S, Dannucci GA, Sharkey NA, Pool RR: The fate of articular cartilage after transplantation of fresh and cryopreserved tissue-antigen-matched and mismatched osteochondral allografts in dogs. *J Bone Joint Surg Am* 1989;71:1297-1307.
5. Czitrom AA, Keating S, Gross AE: The viability of articular cartilage in fresh osteochondral allografts after clinical transplantation. *J Bone Joint Surg Am* 1990;72:574-581.
6. Oakeshott RD, Farine I, Pritzker KPH, Langer F, Gross AE: A clinical and histologic analysis of failed fresh osteochondral allografts. *Clin Orthop* 1988;233:283-294.
7. Zukor DJ, Paitich B, Oakeshott RD, et al: Reconstruction of post-traumatic articular surface defects using fresh small-fragment osteochondral allografts, in Aebi M, Regazzoni P (eds): *Bone Transplantation*. Berlin: Springer-Verlag, 1989, pp 293-305.
8. Garrett JC: Osteochondral allografts for reconstruction of articular defects, in McGinty JB, Caspari RB, Jackson RW, Poehling GG (eds): *Operative Arthroscopy*, 2nd ed. Philadelphia: Lippincott-Raven, 1996, pp 395-403.
9. Mankin HJ, Doppelt SH, Tomford WW: Clinical experience with allograft implantation: The first ten years. *Clin Orthop* 1983;174:69-86.
10. 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.
11. Arnoczky SP, Warren RF, Ashlock MA: Replacement of the anterior cruciate ligament using a patellar tendon allograft: An experimental study. *J Bone Joint Surg Am* 1986;68:376-385.
12. Drez DJ Jr, DeLee J, Holden JP, Arnoczky S, Noyes FR, Roberts TS: Anterior cruciate ligament reconstruction using bone-patellar tendon-bone allografts: A biological and biomechanical evaluation in goats. *Am J Sports Med* 1991;19:256-263.
13. Jackson DW, Grood ES, Arnoczky SP, Butler DL, Simon TM: Freeze dried anterior cruciate ligament allografts: Preliminary studies in a goat model. *Am J Sports Med* 1987;15:295-303.
14. 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.
15. Cordrey LJ, McCorkle H, Hilton E: A comparative study of fresh autogenous and preserved homogenous tendon grafts in rabbits. *J Bone Joint Surg Br* 1963;45:182-195.
16. Thomas ED, Gresham RB: Comparative tensile strength study of fresh, frozen, and freeze-dried human fascia lata. *Surg Forum* 1963;14:442-443.
17. Nikolaou PK, Seaber AV, Glisson RR, Ribbeck BM, Bassett FH III: Anterior cruciate ligament allograft transplantation: Long-term function, histology, revascularization, and operative technique. *Am J Sports Med* 1986;14:348-360.
18. Noyes FR, Barber SD: The effect of an extra-articular procedure on allograft reconstructions for chronic ruptures of the anterior cruciate ligament. *J Bone Joint Surg Am* 1991;73:882-892.
19. Shino K, Inoue M, Horibe S, Hamada M, Ono K: Reconstruction of the anterior cruciate ligament using allogeneic tendon: Long-term followup. *Am J Sports Med* 1990;18:457-465.
20. Indelicato PA, Linton RC, Huegel M: The results of fresh-frozen patellar tendon allografts for chronic anterior cruciate ligament deficiency of the knee. *Am J Sports Med* 1992;20:118-121.
21. Shelton WR, Papendick L, Dukes AD: Autograft versus allograft anterior cruciate ligament reconstruction. *Arthroscopy* 1997;13:446-449.
22. 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* 1996;324: 134-144.
23. Noyes FR, Barber SD, Mangine RE: Bone-patellar ligament-bone and fascia lata allografts for reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am* 1990;72:1125-1136.
24. Noyes FR, Barber-Westin SD: Posterior cruciate ligament allograft reconstruction with and without a ligament augmentation device. *Arthroscopy* 1994;10:371-382.
25. Bullis DW, Paulos LE: Reconstruction of the posterior cruciate ligament with allograft. *Clin Sports Med* 1994;13:581-597.
26. Noyes FR, Barber-Westin SD: Surgical reconstruction of severe chronic posterolateral complex injuries of the knee using allograft tissues. *Am J Sports Med* 1995;23:2-12.
27. Fairbank TJ: Knee joint changes after meniscectomy. *J Bone Joint Surg Br* 1948;30:664-670.
28. Arnoczky SP, McDevitt CA, Schmidt MB, Mow VC, Warren RF: The effect of cryopreservation on canine menisci: A biochemical, morphologic, and biomechanical evaluation. *J Orthop Res* 1988;6:1-12.
29. Shelton WR, Dukes AD: Meniscus replacement with bone anchors: A surgical technique. *Arthroscopy* 1994;10: 324-327.