Allograft Meniscus Transplantation

Background, Indications, Techniques, and Outcomes

Richard W. Kang, BS
Christian Lattermann, MD
Brian J. Cole, MD, MBA

HISTORY

The treatment of meniscal injuries has evolved greatly. Due to the lack of understanding of the biomechanics of meniscal function, meniscal excision used to be a favorable technique.[45] However, current understanding of meniscal function and the natural history of the meniscectomized knee has led to attempts at meniscal preservation.[24] The meniscus plays an important role in load sharing, shock absorption, joint stability, joint nutrition, and overall protection of articular cartilage.[46] In an effort to preserve these biomechanical properties as well as overall knee function, allograft meniscus transplantation has been used in selected patients. Intermediate-term studies have indicated that excellent pain relief and improved knee function can be achieved with rigid adherence to surgical indications and postoperative care.[18,19]

Natural History of Meniscectomy

Meniscal tears cause pain, loss of function, and predispose the knee to articular cartilage degeneration and eventual osteoarthritis. The degree of osteoarthritis is related to the chronicity of meniscal damage, the extent of meniscus loss, associated knee instability, overall alignment, and most importantly, the severity of concomitant articular cartilage injury.*

Meniscal Anatomy and Biomechanics

The menisci are semilunar, wedge-shaped, fibrocartilage structures. The medial meniscus is semicircular in shape with the posterior horn wider than the anterior horn. The lateral meniscus is circular in shape with the anterior horn attaching anterior to the intercondylar eminence and posterior to the anterior cruciate ligament (ACL).

In a normal gait pattern, the knee bears up to six times the body weight.[61] The radial and longitudinal collagen fiber orientation allows the meniscus to direct compressive forces into hoop stress and thus allows the menisci to transmit between 50% and 90% of the joint load during weight bearing.[1,77] Meniscal loss disrupts this function. A loss of as little as 16%-34% increases contact forces by 350%.[64] Particularly, radial meniscal tears extending to the periphery and thus disrupting the hoop-stresses result in tibiofemoral contact forces equivalent to a completely meniscectomized knee.[41]

In ACL insufficiency, the loss of a meniscus will enhance the instability due to loss of its important secondary restraint function.[5,42,69] This may lead to early graft elongation[47,67] and accelerate progression towards osteoarthritis. Allograft meniscus transplantation may therefore be indicated at the time of ACL reconstruction in this particular patient population.[54]

Early arthritic changes after meniscectomy can be evaluated according to radiographic criteria. These so-called "Fairbank's changes" are common radiographic findings after meniscectomy and include a formation of a ridge on the femoral condyle, flattening of the femoral condyle, and joint-space narrowing.[24] A study by Johnson et al[38] with a mean follow-up of 17.5 years reported that 74% of 99 knees with meniscectomies had at least one Fairbank change compared to only 6% in the contralateral knees.

Mr Kang and Drs Lattermann, and Cole are from the Department of Orthopedic Surgery, Rush University Medical Center, Rush Medical College, Chicago, Ill.

Reprint requests: Brian J. Cole, MD, MBA, Depts of Orthopedics and Anatomy & Cell Biology, Rush University Medical Center, 1725 W Harrison, Ste 1063, Chicago, IL 60612.

**12, 23, 30, 36, 48, 56, 58, 59, 63*

The role of meniscal allografts becomes apparent in light of studies that demonstrate fewer arthritic changes in areas covered by allografts, with associated reductions in contact pressures, than areas that are left uncovered.[6,7,13,34,73]

Historical Perspective of Allograft Meniscal Transplantation

Human joint transplantations first began a century ago.[43,44] Although the first allograft meniscus transplantation was performed in 1972 by Zukor et al,[80] the protective effect of allograft meniscus transplantation was not clearly documented before 1997.[22] Advances in graft preparation and sterilization have since improved graft viability, revascularization, and graft survival.[6,7,33,49-51] Some concerns remained due to the nature of allograft tissue transplantation. Meniscal allografts express the Class I and II histocompatibility antigens and therefore are immunogenic.[35] Despite the distinct possibility of an immune response to the allograft tissue, only isolated cases of allograft meniscus transplantation have been identified in which a possible rejection may have played a role. The sequelae reported, however, are clinically not significant.[27,32]

GRAFT PROCUREMENT AND PRESERVATION

The first, and most critical, step in graft procurement is stringent donor screening and selection. The American Association of Tissue Banks has defined a stringent protocol to increase the likelihood of obtaining disease-free grafts.[71] Tissues are screened for bacterial and viral contamination and then are mechanically cleansed. The risk of disease transmission with these techniques is low[11] and may even be lower with the introduction of newer testing techniques including polymerase chain reaction (PCR) and nucleic acid testing.

Modern graft procurement may either occur within 12 hours of death or within 24 hours of death provided that the body has been stored at 4°C. The graft tissue may be preserved in one of four ways: cryopreservation, fresh-frozen, fresh, or lyophilization. Lyophilization is uncommonly used as it is implicated in graft shrinkage, decreased cell viability, and diminished biomechanical properties.[50,78] Cryopreservation involves the use of dimethylsulfoxide to preserve cell viability. The fresh-frozen method includes a rapid cooling to −80°C, which is deleterious to cell viability but does not affect the biomechanical properties of the graft. Fresh grafts are harvested within 12 hours of death under sterile conditions. However, these grafts are logistically difficult to work with as they require transplantation within several days of procurement. Because of the difficulties in working with fresh and lyophilized grafts, fresh-frozen and cryopreserved grafts are more commonly used. In addition, there have been no demonstrated benefits to preservation methods beyond the fresh-frozen process, and to date, this is the most commonly used process for implants.[34]

INDICATIONS

The ideal patient for an allograft meniscus transplantation is one who presents with pain in a meniscal deficient compartment (ie, prior meniscectomy), is not significantly overweight (body mass index <30), has normal alignment, has stable knee ligaments, has normal knee cartilage, and is relatively "young" but skeletally mature. Although alleviating the patient's pain is the primary purpose of allograft meniscus transplantation, it also has the potential to delay the onset of osteoarthritis.

Contraindications include inflammatory arthritis, synovial disease, history of knee infections, immunodeficiency, obesity, systemic metabolic diseases, and skeletal immaturity. The most common contraindications include advanced arthritis (late grade III or IV), flattening of the femoral condyle, or marked osteophyte formation.[28,70,75] As they are considered relative contraindications, comorbidities such as ligamentous instability, malalignment, and cartilage degeneration must be addressed at the time of or prior to meniscus transplantation. For example, patients with known focal chondral defects of the femur or tibia are considered candidates for allograft meniscus transplantation as long as these lesions are appropriately addressed.[2,3] Similarly, patients who have long-standing meniscectomized knees may develop secondary varus or valgus deformities that will have to be corrected with an osteotomy simultaneously or in a staged fashion. Most commonly, there are only subtle degrees of joint space narrowing with some articular or sub-articular changes on magnetic resonance imaging (MRI) and minor macroscopic changes at the time of arthroscopy (Figure 1).

PATIENT EVALUATION

Post-meniscectomy patients usually present with subtle joint line pain, swelling with activity, and knee pain induced by changes in the ambient barometric pressure. At times, they also present with an occasional painful giving-way and crepitus. After taking a detailed history, the physical examination should assess the status of ligament stability, alignment, and the articular cartilage. Evaluation of the location and reason for previous incisions also is critical as many of these patients have undergone prior surgical procedures including ligament reconstructions and attempted meniscal repair. These assessments are important as they may determine modifications in the treatment plan. Generally, patients will have tenderness at the involved joint line,

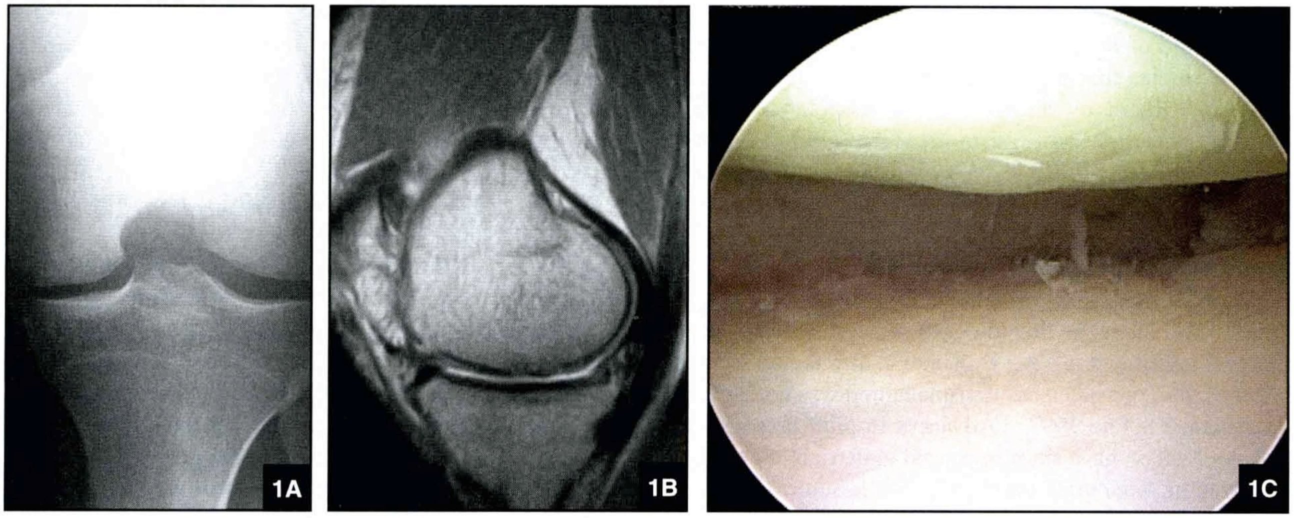

Figure 1. Typical flexion weight-bearing radiograph of a 30-year-old patient following medial total meniscectomy and beginning medial joint line pain. There is a small osteophyte on the medial eminence, beginning squaring of the medial condyle, and a decreased medial joint space (A). The corresponding MRI (sagittal T1-weighted image) shows the missing meniscus and grade II changes along the medial femoral condyle (B). The arthroscopic view of the medial compartment verifies the MRI and radiographic findings. The meniscus is missing in its entirety (C).

full range of motion, minimal osseous changes (palpably or visibly), and potentially, a slight effusion.

Routine radiographs include weight-bearing anteroposterior (AP) view of both knees in full extension, a nonweight-bearing 45° flexion lateral view, and an axial view of the patellofemoral joint. Joint narrowing not seen on extension views may be seen on 45° flexion weight-bearing posteroanterior views.[62] Long-leg alignment radiographs may be taken if malalignment is suspected. Articular cartilage may be assessed via MRI. A three-phase technetium bone scan is rarely indicated when the source of symptoms is uncertain. If the status of the joint cartilage and the amount of meniscus that was previously resected is unclear, it is strongly recommended that a diagnostic arthroscopy be performed to evaluate the knee for an allograft meniscus transplantation. This especially is true if the patient has not had surgical intervention for >1 year wherein which articular cartilage deterioration might have occurred. The diagnostic arthroscopy will help determine whether additional treatment may be necessary at the time of meniscus implantation. Notably, a meniscal allograft and some articular cartilage treatment options (ie, osteochondral allograft transplantation and autologous chondrocyte implantation) are not available off-the-shelf and thus, accurate diagnostic information is required prior to scheduling a definitive implant date.

ALLOGRAFT SIZING

As meniscus allografts are side- and compartment-specific, using the contralateral meniscus is not an acceptable method to estimate allograft size. The best method for estimating the appropriate size of an absent meniscus is with plain radiographs.[55,66] Although newer information is emerging in support of other imaging techniques, MRI and computed tomography (CT) were not recommended previously as they had been implicated in misjudging the size of the allograft.[15,39] The surgeon should also be aware of the sizing techniques used by the tissue provider to ensure a size match. The technique described by Pollard et al[55] is commonly used. Preoperatively, measurements are made on AP and lateral radiographs, with magnification markers placed on the skin at the level of the proximal tibia. The meniscal width is calculated based on the width of the compartment as seen on an AP radiograph after correction for magnification. The meniscal length is based on a lateral radiograph using the sagittal length of the tibial plateau. Following correction for magnification, the length is multiplied by 0.8 for the medial meniscus and by 0.7 for the lateral meniscus. This technique has been shown to lead to a size match in at least 95% of cases, which is crucial in optimizing graft survival and protection of the articular surfaces (Figure 2).[76]

TECHNIQUES

We prefer arthroscopic allograft meniscus transplantation versus an open allograft meniscus transplantation because of reduced surgical morbidity and more precise meniscal repair techniques.*

*14, 16, 20, 25, 26, 28, 50, 72, 74

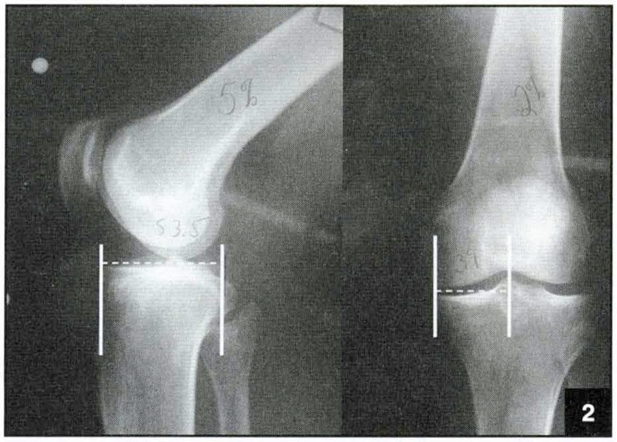

Figure 2. The allograft meniscus requires correct sizing. This is done using AP and lateral radiographs with sizing markers that allow for the determination of the amount of magnification. The meniscus width is determined on the AP view by measuring the distance from the peak of the medial or lateral eminence to the border of the tibial metaphysis (white lines). Osteophytes need to be disregarded for this measurement. The meniscus length is determined in the lateral view by measuring the distance between a tangential along the anterior and posterior border of the tibial plateau (white lines). Note the magnification factor marked on the radiograph.

General Considerations

There are two techniques to anchor a meniscal allograft: bone bridge and bone plugs. Both techniques require the meniscus to be securely anchored to the anterior and posterior horns.[4,17,53] Soft-tissue fixation with bone, as opposed to soft tissue alone, is preferred because of its superior load transmission properties.[4,17,53] The bone bridge technique rigidly fixes the distance between the anterior and posterior horns, and may be used for medial and lateral meniscus transplants. The bone plug technique allows for minor adjustments to match the variable position of the anterior horn.[9,40] However, this technique can only be used for medial meniscus and not for lateral meniscus transplants because of the proximity (about 1 cm) of the anterior and posterior horns on the lateral side that risks tunnel communication and therefore compromises bone fixation.[37] We use the bridge-in-slot technique exclusively as it is reproducible, efficient, maintains the native anatomy of the meniscus, can be performed in skeletally immature patients if necessary, and is relatively accommodating when performing concomitant procedures such as osteotomy or ACL reconstruction.[25]

Patient Positioning and Preparation

After induction of general anesthesia, prophylactic intravenous antibiotics are administered. Next, an examination under anesthesia is performed to confirm ligament stability. The patient is placed supine with the involved leg placed in a proximal thigh leg holder with a tourniquet on but not inflated. Initially, a diagnostic arthroscopy is performed to rule out any significant chondral injuries in the involved compartment. The residual meniscal tissue is debrided to a 1- to 2-mm peripheral rim to stimulate a healing response at the meniscocapsular interface.

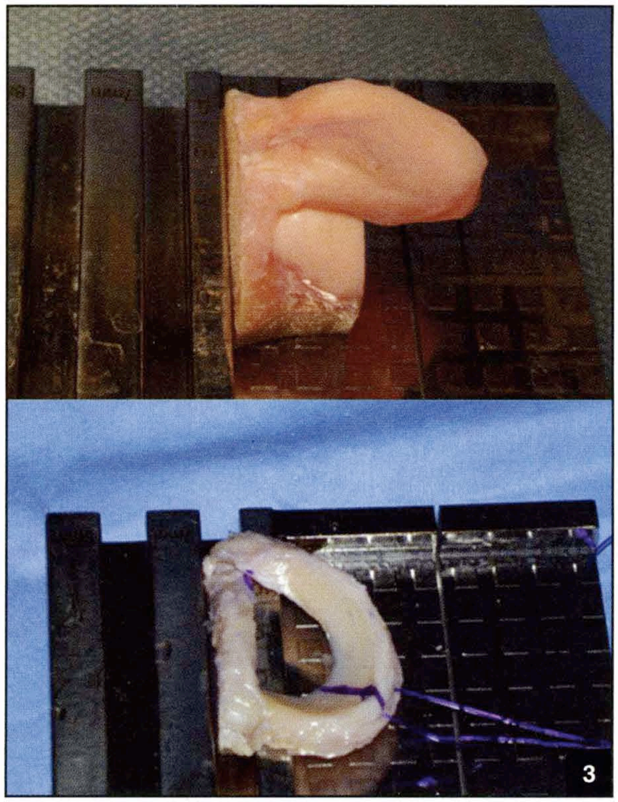

Figure 3. The allograft meniscus is thawed and prepared for the bridge-in-slot technique using a metal cutting block (Arthrex, Naples, Fla). This cutting block enables the surgeon to cut the bone bridge exactly to an 8-mm wide and 10-mm high bone block.

Allograft Preparation

The allograft is sent from the tissue bank as a hemiplateau with the meniscus attached. If needed, the graft is thawed in normal saline or lactated Ringer's solution. Nonmeniscal soft tissue is removed to clearly delineate the anterior and posterior horns. The bone bridge then is cut to 7-8 mm in width and 10 mm in height. The bridge width is undersized by 1 mm to facilitate its passage through the slot. The posterior bony wall of the bridge should be flush with the posterior aspect of the soft tissue of the posterior horn to allow posterior seating of the graft. A 0-PDS vertical mattress traction suture is placed at the junction of the posterior- and middle-thirds of the meniscus graft to facilitate intra-articular positioning. The bridge is tested for ease of passage through calibrated troughs (Figure 3).

Figure 4. The mini-arthrotomy is performed just medial to the patellar tendon. The arthroscopic portals as well as the mini-arthrotomy and the medial incision for the inside-out repair are seen.

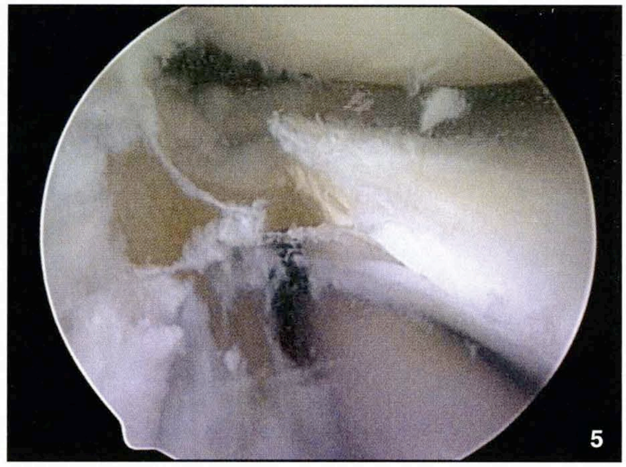

Figure 5. The burr is used to create a provisional trough along the medial aspect of the medial tibial spine. This trough serves as the guiding trough for the cutting guide.

Figure 6. The cutting guide is inserted along the provisional trough and hooked on the posterior horn insertion site of the medial meniscus.

Figure 7. The arthroscopic box cutter is used to create a box-shaped trough.

Bridge-in-Slot Technique

Detailed descriptions of the bridge-in-slot technique are provided elsewhere.[20,25] In brief, standard arthroscopy portals are established. Following meniscectomy and meniscal rim preparation, a slot is created directly in line with the anterior and posterior horns of the involved compartment. A mini-arthrotomy may either be made through the patellar tendon or adjacent to it in line with the anterior and posterior horns (Figure 4). Electrocautery is used to mark a line between the centers of the horn footprints. A 4-mm burr is used to mark a superficial reference slot along the line just created. This slot should be approximately the depth of the burr and should be parallel to the sagittal slope of the tibia (Figure 5). Next, a drill guide is placed into the slot and hooked onto the posterior tibia to measure the dimensions of the slot (Figure 6). A guide wire is drilled parallel to the tibial slope at the appropriate depth. Placement of the guide wire and subsequent reaming may be performed under fluoroscopy. The guide wire is advanced up to, but not through, the posterior edge of the tibial plateau. An 8-mm cannulated reamer is advanced over the guide wire and the roof of the reamed socket is removed with an arthroscopic rongeur. The round socket with its overlying rectangular provisional reference slot is transformed into a definitive slot with an 8×10-mm box cutter (Figure 7). Finally, a rasp is used to smooth out the edges of the slot and thus help avoid impingement of the grafted bone bridge (Figure 8).

Allograft Insertion

Using zone-specific meniscus repair cannulae, traction sutures on the graft are shuttled through the posterior incision. The allograft is inserted through the arthrotomy

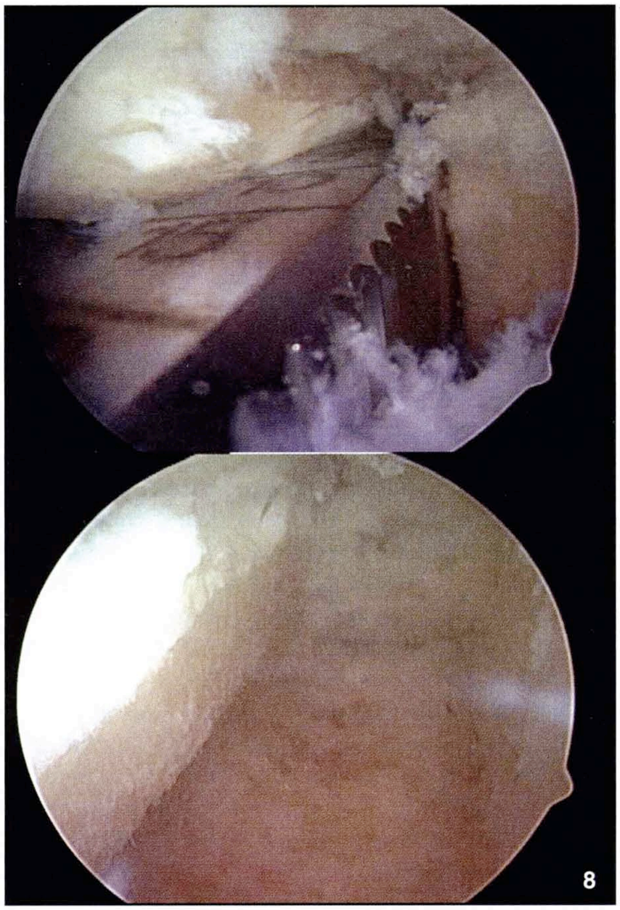

Figure 8. A 7-mm followed by an 8-mm rasp is used to widen the trough to an accurate fit. The bottom picture shows the perfectly prepared slot.

and aligned with the slot while the meniscus is positioned by pulling on the traction sutures and cycling the knee. Simultaneous varus or valgus stress will facilitate graft insertion by distracting the recipient compartment. Once the bone bridge is properly positioned, a guide wire is inserted between the bone bridge and more central (midline) wall of the slot. Next, a tap is used over the guide wire to create a pilot hole for an interference screw while the bone bridge is held in place by a periosteal elevator. A 7×28-mm or 8×28-mm interference screw is inserted while maintaining tight control over the bone bridge position (Figure 9).

A final arthroscopic examination is performed to confirm proper graft placement and size (Figure 10). The graft is secured with 8-10 vertically placed 2-0 nonabsorbable mattress sutures placed from posterior to anterior, dorsally and ventrally on the meniscus with a standard inside-out meniscal repair technique. As an alternative, all-inside meniscal repair devices may be used to secure the most posterior aspect of the meniscus to minimize the risk for neurovascular injury.

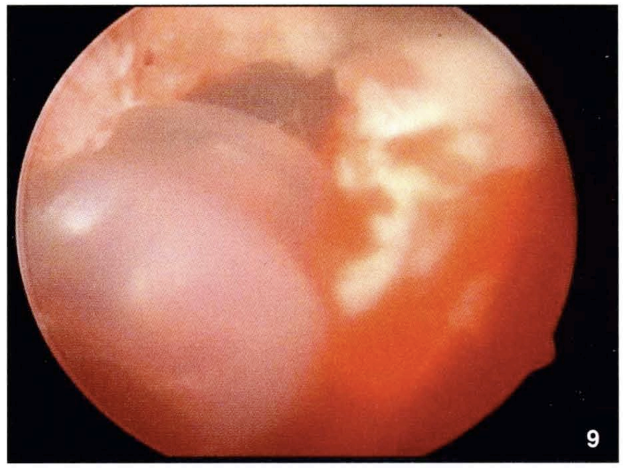

Figure 9. A bioabsorbable interference screw is used to wedge the bone block against the lateral wall of the bony slot.

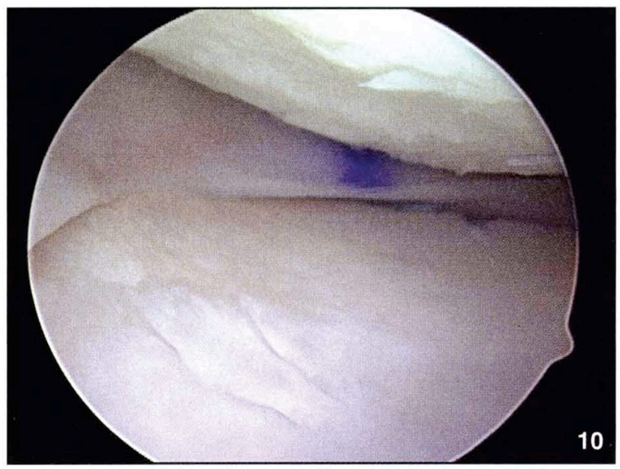

Figure 10. The meniscus is visualized and proper placement is verified.

COMBINED PROCEDURES

Comorbidities such as malalignment, ligament instability, or cartilage defects will need to be addressed either simultaneously or in staged procedures. The following describes the technique and algorithm for conducting these advanced techniques.

Allograft Meniscus Transplantation and Corrective Osteotomy

A realignment osteotomy is indicated when the recipient compartment is under more than physiologic compression.[29] For cases with medial meniscal deficiency and varus alignment, a combined meniscus transplantation and high tibial osteotomy is indicated (Figure 11). In this situation, the mechanical axis should be corrected to just beyond neutral. For cases with lateral meniscal deficiency and valgus alignment, a distal femoral osteotomy is indi-

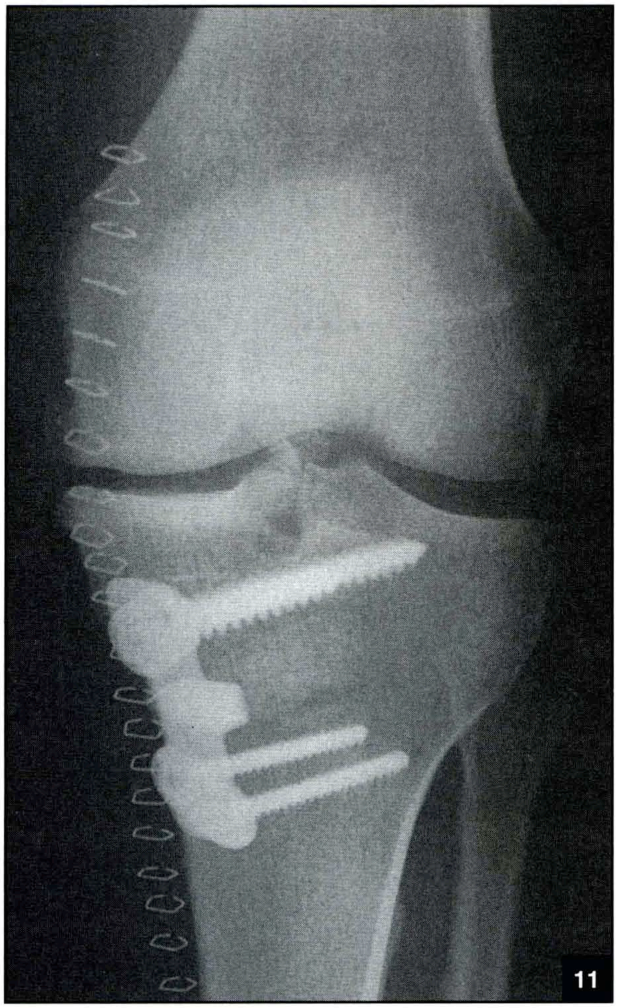

Figure 11. Immediate postoperative radiograph of a patient after combined medial meniscus allograft transplant and high tibial osteotomy using the Puddu plate (Arthrex, Naples, Fla). The meniscus allograft had to be performed first in this case due to the excessive valgus stress that would otherwise have to be put on the osteotomy during insertion and fixation of the meniscus. Note the proximity of the proximal screw to the meniscal bone block. This has to be carefully watched during the osteotomy to ensure the meniscal allograft is not dislodged.

cated along with the meniscus transplantation. All steps of the meniscus transplant are completed prior to performing the osteotomy.

Allograft Meniscus Transplantation and ACL Reconstruction

As ligament instability is a contraindication to meniscus transplantation alone, it is important to evaluate the ligament preoperatively. Assessments include a physical examination, careful history, MRI and radiographs, and especially an arthrometric evaluation. An examination under anesthesia may be more reliable than while the patient is awake.

The biomechanical interdependence between the meniscus and ACL is well known.[54] The success of an ACL reconstruction depends on an intact medial meniscus to minimize anteroposterior stress.[42,67] In turn, an intact ACL protects the menisci and articular cartilage.[8,10] In the appropriate candidate, a simultaneous ACL reconstruction with meniscus transplantation has proven to be beneficial.[79]

A hamstring graft or Achilles allograft for ACL reconstruction can facilitate graft passage by allowing for a smaller-diameter tibial ACL tunnel. With the bone bridge technique, the tibial ACL tunnel is drilled first. This tunnel is positioned toward the contralateral compartment of the meniscus transplant as much as possible without compromising the anatomic position. In addition, a longer tunnel is preferred to create as round a tibial intra-articular orifice as possible. Next, the ACL femoral tunnel is drilled in the traditional position. The meniscal slot is created, noting that there will be some confluence of the tibial ACL tunnel with the anterior third of the meniscus slot. This partial intersection of the tibial tunnel with the meniscus bone bridge will not be problematic.[18] The ACL is passed and fixed in the femur. The soft-tissue portion of the graft is manually displaced with a probe to clear the graft from the meniscus slot. The meniscus is introduced and reduced into its recipient slot. The ACL graft is tensioned and the tibial portion is fixed. Finally, the interference screw is passed to fixate the meniscal bone bridge and the meniscus is repaired as described previously (Figure 12).

Allograft Meniscus Transplantation and Cartilage Restoration

Combining cartilage restoration procedures (ie, autologous chondrocyte implantation or osteochondral allograft transplantation) with allograft meniscus transplantation requires careful planning of the surgical steps to avoid one procedure impairing the other. In general, we prefer to simultaneously treat localized articular cartilage damage and meniscal allograft transplantation.

REHABILITATION

The postoperative rehabilitation plan is not universal across the various programs. The senior author (B.J.C.) recommends range of motion from 0° to 90° with protected weight bearing with a hinged knee brace during the initial 4 weeks. Nonweight-bearing flexion beyond 90° is immediately permitted. After this initial period, full weight-bearing range of motion is allowed and activities such as cycling, swimming, and closed-chain kinetic exercises may begin. Forced flexion and pivoting activities should be avoided. Patients may return to running at 4-6 months. At 6-9 months, patients are encouraged to return to full activities provided that the strength is at least 80%-85% of normal.

COMPLICATIONS

Complications generally are rare and may lead to graft removal. Otherwise, the complications are similar to that of meniscal repair, including incomplete healing, persistent symptoms, infection, arthrofibrosis, and neurovascular injury.

OUTCOMES

A review of the literature demonstrates that allograft meniscus transplantation generally leads to 85% good to excellent results. The risk for graft failure increases with irradiated grafts, uncorrected malalignment, osteoarthritis, and lack of bone anchorage of the allograft.[52] The Table summarizes the clinical results of allograft meniscus transplantation.

Physical appearance of the graft does not seem to be clearly correlated with outcome. Milachowski et al[50] found that graft shrinkage did not affect outcomes. Moreover, Stollsteimer et al[72] described significant pain relief in all 23 patients despite average graft shrinkage of 37%.

Articular cartilage degeneration is associated with poorer outcomes. Garrett[28] reported that 35 (81%) of 43 patients were asymptomatic at minimum 2 years, with most of the failures occurring in knees with grade IV chondromalacia. Shelton and Dukes[68] found that significant decreases in pain were reported for patients who had <grade II arthritic changes, whereas patients with degenerative compartments had only slight improvement in symptoms.[68]

Absence of allograft bone anchorage also is correlated with poorer outcomes. Noyes and Barber-Westin[52] reported on 96 grafts that were secured with bone in the posterior horn but not in the anterior horn. Clinical failure occurred in 58% of the grafts, 31% healed partially, and only 9% healed completely. Rodeo[60] reported that 14 (88%) of 16 grafts with anterior and posterior horn bone fixation were successful, whereas only 8 (47%) of 17 grafts without bone fixation were successful.

Combining procedures to treat comorbid conditions that would otherwise be contraindications to allograft meniscus transplantation has been successful. A study by Zukor et al[80] has found that 26 (79%) of 33 patients who have had a combined osteochondral allograft with meniscus transplantation were clinically successful at 1-year follow-up. Cole et al[19] recently reported that meniscus transplantation alone or in combination with other reconstructive procedures to address concomitant articular cartilage injury results in reliable improvements in knee pain and function at minimum 2-year follow-up. They have found that 90% of patients were classified as normal or nearly normal using the International Knee Documentation Committee (IDKC) knee examination score at final follow-up. Sekiya et al[65] reported that 24 (86%) of 28 patients had normal or near normal IKDC scores subsequent to ACL reconstruction and meniscus transplantation. Additionally, approximately 90% of patients had normal or near normal Lachman and pivot shift examinations and had an average maximum KT arthrometer (MEDmetric Corp, San Diego, Calif) side-to-side difference of 1.5 mm. Cameron and Saha[14] performed an osteotomy along with allograft meniscus transplantation in 34 of 63 patients. Patients with realigned knees had a success rate that was comparable to the group as a whole, with good to excellent results in 85% and 87%, respectively.

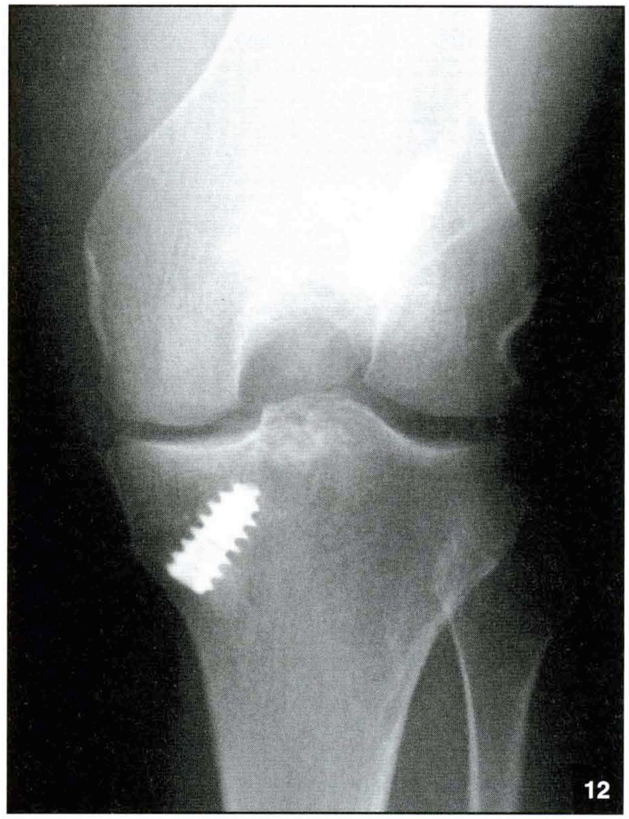

Figure 12. Radiograph of a patient 3 years after combined ACL reconstruction and lateral meniscal allograft. The medial joint space is well maintained.

CONCLUSIONS

Allograft meniscus transplantation is a reasonable treatment alternative for patients who have a meniscus de-

TABLE
RESULTS OF ALLOGRAFT MENISCUS TRANSPLANTATION

Author	Follow-up	N	Results
Milachowski et al[50] (1989)	14 months	22 patients	87% satisfied
Zukor et al[80] (1989)	12 months	33 allografts	79% success
Garrett[28] (1993)	2-7 years	43 allografts	74% success
van Arkel and de Boer[74] (1995)	2-5 years	23 patients	87% satisfied
Goble et al[31] (1996)	2 years*	18 patients	94% success
Cameron & Saha[14] (1997)	31 months	67 allografts	87% good/excellent
Cole & Harner[21] (1999)	24 months	22 allografts	88% success
Carter[16] (1999)	24 months	46 allografts	91% success
Stollsteimer et al[72] (2000)	40 months	22 patients	100% improvement
Rodeo[60] (2001)	2 years*	33 patients	88% success with bone fixation and 47% success without bone fixation
Rath et al[57] (2001)	5.4 years	22 patients	64% success
Cole et al[19] (2006)	2 years*	44 allografts	77.5% satisfied

*Minimum

ficient knee and no more than grade II or early grade III arthrosis. Clinical studies support the procedure's effectiveness in alleviating pain, swelling, and improving functional outcomes. However, results are poor for patients with advanced arthrosis and remains as the primary contraindication for allograft meniscus transplantation. Despite the technical difficulty of performing meniscal transplantation, intermediate-term studies have demonstrated the efficacy of this procedure with high levels of patient satisfaction provided that the relevant comorbidities have been appropriately treated.

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