Failed ACL Reconstruction and Meniscus Deficiency

Background, Indications, and Techniques for Revision ACL Reconstruction With Allograft Meniscus Transplantation

Winslow Alford, MD and Brian J. Cole, MD, MBA†*

Abstract: In the proper setting, a single stage meniscus transplantation and revision ACL results in a therapeutic synergy. The stability from the revision ACL reconstruction protects the meniscus transplant, and the meniscus transplant provides a secondary restraint to protect the revised ACL reconstruction. This is particularly true in the case of the posterior horn of the medial meniscus. With proper patient selection, thorough preoperative planning, and meticulous attention to technique, this combined treatment can provide an optimal outcome to the patient with a failed ACL reconstruction and a deficient meniscus. This article discusses the indications, patient evaluation, and technical considerations combining these 2 procedures, particularly with respect to tibial tunnel placement.

Key Words: revision anterior cruciate ligament reconstruction, meniscus transplant, allograft, surgical technique, secondary restraint, bone plug technique, slot technique, osteotomy, tibial tunnels

(*Sports Med Arthrosc Rev* 2005;13:93–102)

There are potentially 3,000 to 10,000 revision anterior cruciate ligament (ACL) surgeries performed each year in the United States.[1] One well-recognized factor that contributes to primary anterior cruciate ligament (ACL) success is the status of the menisci at the time of reconstruction.[2] In certain previously menisectomized patients, a meniscus transplant may be indicated at the time of a revision ACL reconstruction. The purpose of this study is to examine the indications for meniscus transplantation in the setting of a revision ACL reconstruction, and to review some technical considerations of combining a revision ACL reconstruction with a meniscus transplant as a single stage procedure. In properly selected patients, a meniscus transplant and revised ACL reconstruction are mutually beneficial procedures, wherein the meniscus transplant will provide pain relief and additional stability to the revised ACL and the revised ACL will provide knee stability and protect the meniscus transplant. Clinically, with appropriate indications and attention to surgical technique, this combination of procedures should lead to a painless stable knee with excellent function and a high level of patient satisfaction.

From *West Bay Orthopedics Sports Medicine Division, Warwick, RI; and †Departments of Orthopedics, Rush Cartilage Restoration Center, Rush University Medical Center, Chicago, IL.

Reprints: Brian J. Cole, MD, Rush University Medical Center, 1725 W. Harrison Street, Suite 1063, Chicago, IL 60612 (e-mail: bcole@rushortho.com).

BIOMECHANICS

The posterior horn of the medial meniscus contributes a substantial block to posterior-anterior translation of the tibia on the femur.[3,4] Prior medial menisectomy or incompetence of the posterior horn of the medial meniscus following primary ACL reconstruction has been associated with graft elongation and joint laxity.[2] The important role of menisci in load transmission and articular cartilage protection is well documented.[5–8] It has been shown that meniscus transplants improve load transmission compared with menisectomized knees,[9,10] and they have long-term protective effect on articular cartilage as long as secure bone anchorage of the anterior and posterior horns are obtained.[11] Competent menisci play a principle role in articular cartilage health following revision ACL surgery, and avoiding degenerative changes and pain relief are long-term goals following revision ACL reconstruction.

The biomechanical interdependence between an ACL reconstruction graft and the menisci is well documented,[12] and has been shown to play an important role in obtaining a successful outcome following both primary and revision ACL reconstruction. In primary ACL reconstruction, successful results are expected, but still are not universally predictable. A review of 482 patients with up to 15 years follow-up (mean 7.6 years) after primary ACL reconstruction demonstrated that the condition of the menisci at the time of ACL reconstruction was a key predicting factor of long term outcome.[2,13] Simultaneous meniscus transplantation and ACL reconstruction have been shown to be mutually beneficial in properly selected patients.[14,15] The same contributions of the menisci toward successful primary reconstruction are relevant in the setting of a revision ACL.

Thus, a successful ACL reconstruction relies on an intact medial meniscus to minimize anterior-posterior stress[2,16] and an intact ACL, in turn, protects menisci and articular cartilage.[17,18] This important interdependence is specifically highlighted when patients present with failure of their ACL reconstruction and a history of prior menisectomy with complaints of instability and/or pain.

PATIENT EVALUATON AND INDICATIONS

When revising a failed ACL reconstruction one must determine that the principal reason for failure is in fact meniscal deficiency. Clinically, these patients typically present with a history of a technically well-performed ACL reconstruction and a prior medial menisectomy and, after having done well for a period of time, they complain of worsening atraumatic instability with or without medial joint line pain. Occasionally, patients will not complain of instability, but rather isolated medial joint line pain and activity related swelling. Finally, a subset of these patients will present with a prior lateral menisectomy and complain of lateral joint line pain with activity related swelling without recurrent instability. The most common presentation, however, is a scenario where progressive elongation of the ACL occurs as measured by knee arthrometer testing (ie, KT-1000 or 2000). When complaints of pain supercede those of instability, a knee with a side-to-side difference of 3 mm or more as measured by a knee arthrometer must be seriously considered for single-stage revision ACL reconstruction and meniscus transplantation to provide maximal mutual protection to the ACL graft and the meniscal transplant. Likewise, a patient undergoing a revision ACL reconstruction with a known deficient meniscus, particularly on the medial side, should be considered for meniscal transplant combined with revision ACL reconstruction.

Conventional indications for meniscus transplantation include patients with a prior menisectomy, intact articular cartilage (ie, less than Outerbridge grade III changes[19]), normal alignment, and a stable joint. Contraindications include inflammatory arthritis and previous intraarticular infection. Contraindications to meniscus transplantation for which there are surgical solutions include focal chondral disease, varus or valgus malalignment, and ligament instability. When the only pathology that exists is meniscus deficiency and a lax or failed ACL reconstruction, these are routinely corrected simultaneously.

Timing issues become increasingly complex when multiple corrective measures are pursued. Requisite to implementing any option to restore the articular surface or meniscus is an intact functioning ACL. Thus, not infrequently when multiple pathologies exist in addition to a failed ACL (ie, focal chondral disease, meniscus deficiency, and malalignment), the senior author (BJC) begins the reconstruction effort by re-establishing ligamentous stability and then returns within 12 to 16 weeks to perform cartilage resurfacing, meniscus transplantation, and, possibly, realignment. This will minimize any complications related to stiffness or motion loss that may normally occur as a complication of ACL reconstruction. Similarly, realignment procedures such as high tibial osteotomy (HTO) and distal femoral osteotomy (DFO) are better performed at the time of cartilage resurfacing due to their similar postoperative weight bearing restrictions.

Physical examination should confirm the absence of significant mechanical axis malalignment or a medial or lateral thrust. Range of motion is typically preserved. Joint line tenderness and an effusion may be appreciated. Ligament and arthrometer testing should confirm a non-functional ACL. It is critical to assess for other occult instability patterns that may be associated with ACL failure (ie, neglected posterolateral corner insufficiency). Appropriate radiographs must be obtained and include a 45° flexion posterior to anterior standing weightbearing radiograph,[20] a flexion non-weightbearing lateral radiograph, a patella view, and a long-leg (hip-to-ankle) weight bearing alignment view. Specifically, one should evaluate for joint space narrowing, tunnel placement and enlargement, subchondral sclerosis, femoral or tibial condyle flattening, and mechanical axis deviations beyond 50% of the ipsilateral compartment. Routine MRI may confirm the absence of the meniscus, an attenuated or torn ACL, and subchondral changes that may signify degenerative change beyond which is acceptable to tolerate a meniscus allograft.

GRAFT SELECTION

When performing a revision ACL reconstruction with an allograft meniscus transplant, we typically use fresh-frozen non-irradiated bone-patellar-tendon-bone allograft tissue to reconstruct the ACL. The benefits of this graft type include reduced morbidity associated with autograft harvest, reduced surgical time, the ability to create custom bone blocks to fill enlarged femoral or tibial tunnels, bone-to-bone healing with interference screw fixation, and some flexibility in choosing the length of the allograft that becomes a factor when performing simultaneous procedures such as opening medial wedge tibial osteotomies. Alternatively, hamstring autografts may offer the potential advantage of smaller tibial tunnels, but typically, efforts are made at utilizing the previous tibial tunnel providing it is in an acceptable position to avoid creating multiple metaphyseal tunnels.

For meniscal transplantation, allograft tissue is the only option. Currently, there is no demonstrable benefit of fresh-frozen meniscal allografts over cryopreserved meniscal allografts.[21] Lyophilized or fresh grafts are rarely used. Detailed protocols established by the American Association of Tissue Banks for procurement and tissue testing minimize disease transmission risks of meniscal allografts. Rigid donor screening, nucleic acid testing, polymerase chain reaction sampling, and aseptic processing has lead to negligible risks for disease transmission. For example, the current risk of HIV transmission is estimated to range between 1 in 3 to 8 million when proper screening protocols are followed.[15,22] More importantly, one should be familiar with the tissue bank that they are dealing with to understand the source of their tissue, the policies that they follow, and the procurement and sizing techniques used. If possible, it is recommended that both the ACL allograft and meniscal allograft be obtained through a single tissue bank. It is unrealistic to expect both grafts to come from the same donor.

Meniscal allografts are side- and compartment-specific. Plain radiographs are most commonly used for sizing.[23,24] When corrected for magnification, the meniscal width is determined by measuring the distance from the center of the corresponding tibial eminence to the periphery of the tibial plateau on an anteroposterior radiograph. Meniscal length is measured on the lateral radiograph as the sagittal length of the tibial plateau; to correct for anatomic differences in the relationship of the anterior and posterior horns of the medial and lateral meniscus, the medial meniscus measurement is multiplied by 0.8 and the lateral meniscus measurement by 0.7.[15,24] These measurements are then compared with the soft tissue measurements provided by the tissue bank. Typically, one can accept a slightly larger meniscus than necessary (up to 3–4 mm), but one must be cautious about accepting menisci that are significantly smaller than what is measured (ie, more than 2 mm in any dimension). Intraoperatively, if the graft is judged by the surgeon to be sized incorrectly or the incorrect meniscus altogether is provided (eg, medial rather than a lateral, or left rather than right), the meniscus should not be used.

SURGICAL TECHNIQUE

The surgical steps involved when performing a combined meniscus transplant and revision ACL reconstruction depend on the technique chosen (ie, bone plugs versus bone bridge) and whether it is a medial or lateral meniscus allograft. It is essential that the meniscus be placed in an anatomic position if it is to replicate an intact host meniscus. Arthroscopic techniques are routinely used because of the reduced surgical morbidity and improved accuracy, and have been thoroughly described elsewhere as isolated procedures.[25–34] Despite the complexity of these cases, we routinely perform them in an out-patient setting. Although securing the graft with soft tissue alone is technically easier, load transmission and graft survival is superior when the graft is secured with bone to bone fixation.[10,35,36] Either bone plugs or a bone bridge in the form of a "trough," "slot," or "keyhole" (Fig. 1) is used to anchor the anterior and posterior horns. A step-by-step illustrated technique of isolated meniscal transplantation by bone-plug, slot, or keyhole technique has been described elsewhere and is not the focus of this review.[37–40]

Prior to thawing the allografts, an examination under anesthesia should confirm the presence of an asymmetric pivot shift and arthroscopy should confirm the relative absence of the meniscus and that there are no additional contraindications present (ie, focal chondral defects in the involved compartment). The initial steps for medial and lateral meniscal transplantation are identical. The host meniscus is debrided arthroscopically to a 1 to 2 mm peripheral rim until punctuate bleeding occurs. An incision placed one-third above the joint line and two thirds below the joint line is made on the medial or lateral side of the knee in line with the epicondyle to facilitate inside-out meniscus repair. External palpation of a probe arthroscopically placed directly on the bleeding remnant of the meniscal rim, and transillumination with the arthroscopic light will allow for precise placement of the incision. The dissection should extend to the capsule and the respective head of the gastrocnemeus muscle must be elevated to accommodate a retractor to protect the neurovascular structures during suture needle passage. The meniscus is thawed at this time.

Because visualization is typically excellent early in the procedure, we prefer to prepare the host tibia prior to addressing the failed ACL. Often, we will use bone plugs on the medial side[29] and a bone bridge in slot technique on the lateral side.[30] The bone plug technique facilitates minor adjustments in the position of the anterior and posterior horn due to their anatomic variability.[41–43]

With relatively minor adjustments in the bone bridge and a well placed tibial tunnel, a bridge in slot technique can be performed on the medial side, but it is typically more technically challenging to perform. This is because the ACL

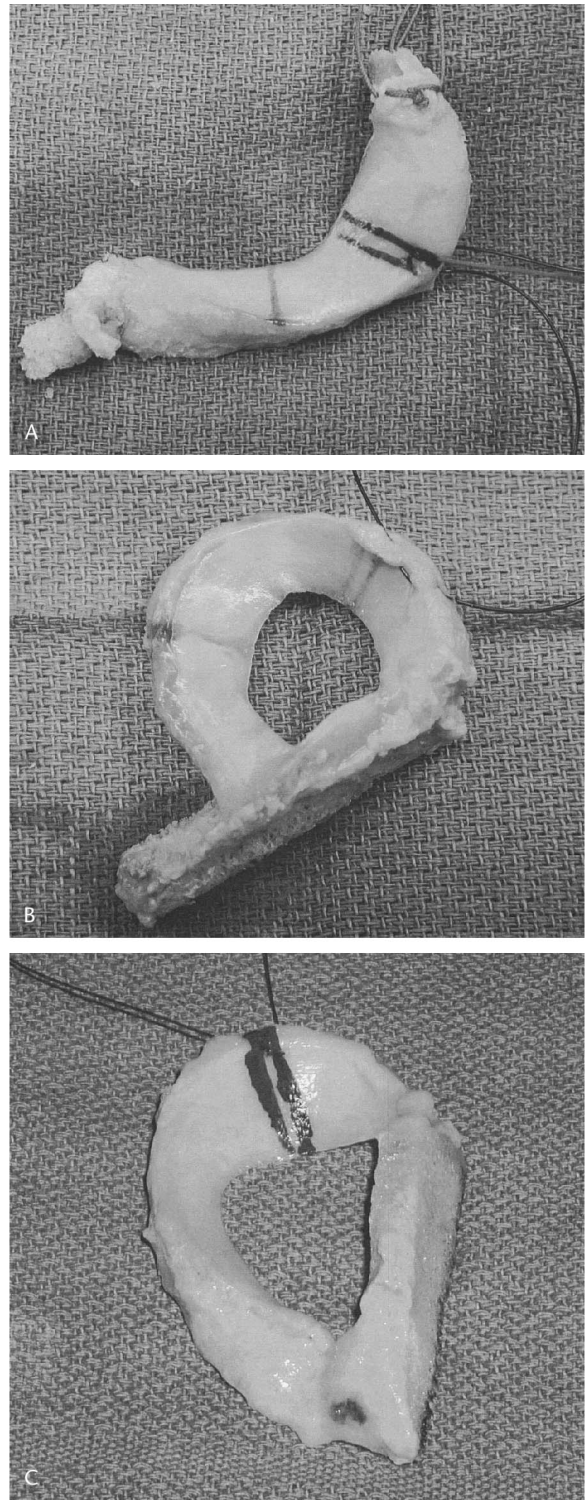

FIGURE 1. Intraoperative examples of meniscal preparation using the (A) bone plug technique, (B) key hole technique, and (C) slot technique. Note the traction suture placed at the junction of the posterior and middle third of the meniscus.

tibial tunnel and graft often intersect part of the bone bridge and maintaining the integrity of the bridge may become difficult. In a revision reconstruction, the original ACL tibial tunnel is often not anatomically placed, which may increase the likelihood of directly interfering with the tibial slot. Whenever possible, however, we do prefer to use the bridge in slot technique due to its simplicity and the fact that the relationship between the anterior and posterior horns is accurately maintained.[30] On the lateral side, the relatively close proximity of the anterior and posterior horns essentially precludes the use of bone plugs.

Using bone plugs for the medial meniscus creates a risk of tunnel communication and accentuates ACL fixation stress risers created by revision tibial tunnels, particularly if a 3-tunnel technique is used.[37] This is particularly true with respect to the posterior horn bone tunnel which originates from a location near the ACL tibial tunnel.[40] If possible, we plan to use the ACL tibial tunnel already present within the tibia. Alternatively, we will choose a short bone-patellar tendon-bone (BTB) allograft or hamstring tendons to reconstruct the ACL through a shorter tibial tunnel (ie, lower angles [45° to 55°] on the tibial guide). In contrast, the posterior horn medial

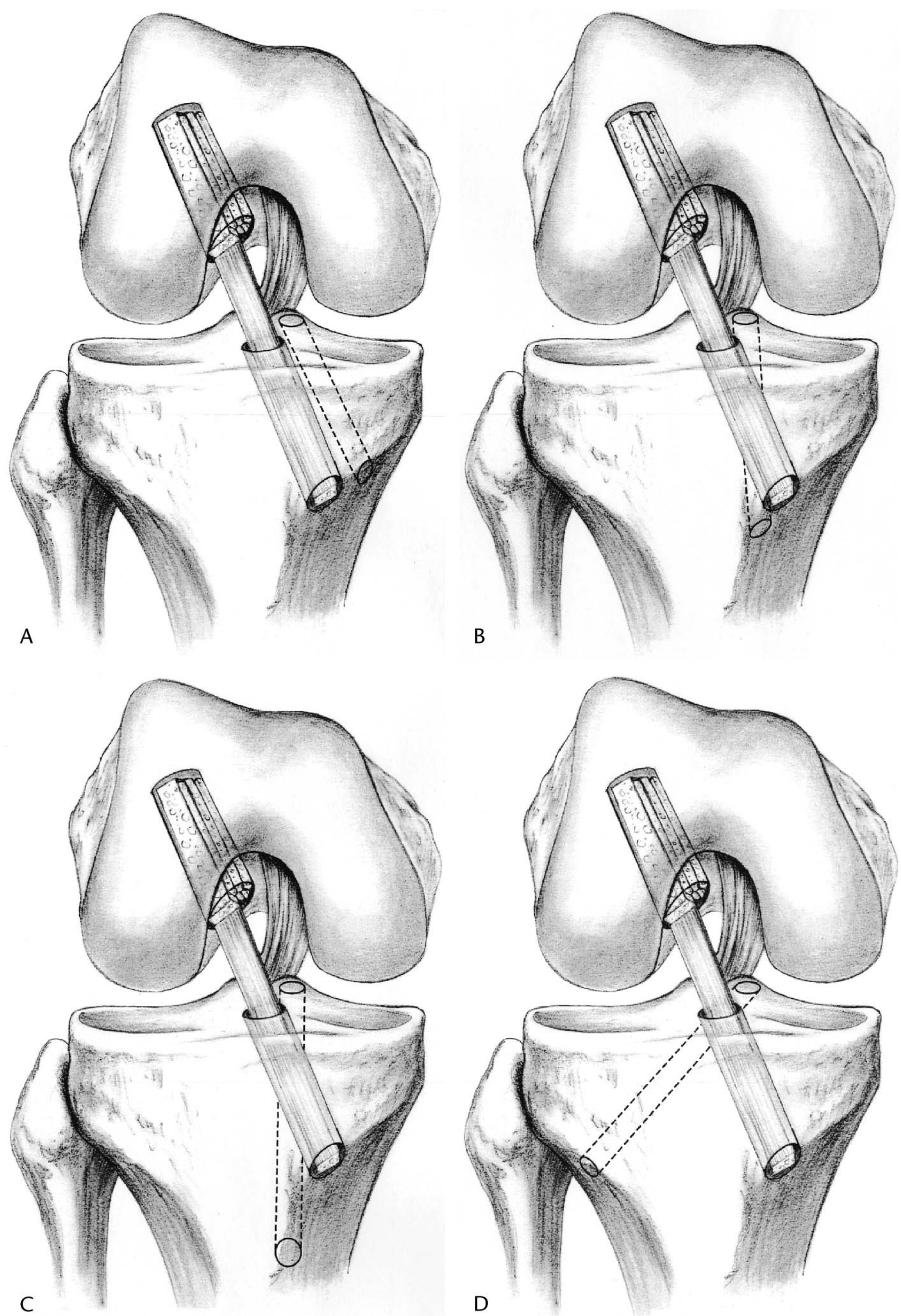

FIGURE 2. Schematic drawings demonstrating the relationship of the ACL tibial tunnel relative to the posterior horn meniscal tibial tunnel. Drawings demonstrate the posterior horn meniscal tunnel being placed (A) medial, (B) in-line, (C) anterocentral and (D) lateral to the ACL tibial tunnel. Typically, placing the tunnel anterocentral or lateral to the tibial tunnel minimizes the chances for tunnel communication. (Illustrations created by Kristen Wienandt).

meniscus tibial tunnel is drilled to be as long as practically possible (the tibial guide is set between 60° to 65°). Tunnel length differences will maximize the divergence of these tunnels, and reduce the chances of creating communicating tunnels or a common entrance in the anteromedial tibia. In addition, choosing the smallest tunnel diameters possible will reduce the chances of tunnel communication. Thus, we will often use an 8-mm posterior horn tunnel and a 9-mm ACL tunnel within the tibia.

There are essentially 4 options for placement of the posterior horn medial meniscus tibial tunnel relative to the ACL tibial tunnel: medial, in-line, anterocentral, and lateral (Fig. 2). Placing the tunnel medial to the ACL tibial tunnel compromises the medial tibial plateau because of the acute angle the reamer makes as it enters the tibia, and often it creates an unnecessarily large area of subchondral bone loss adjacent to the entrance point into the joint. In addition, the trajectory that the traction suture and bone plug make as they are pulled into the tunnel from outside the joint tends to distort the posterior horn of the meniscus during terminal fixation. If one can truly achieve tunnel divergence by using substantially different tibial guide angles for both tunnels (ie, angles that differ by at least 10°), then any of the remaining techniques can be successfully used to properly position the posterior horn tunnel and the tibial ACL tunnel (Fig. 3). Unfortunately, placing the posterior horn tunnel in-line with the ACL tibial tunnel often results in some tunnel communication which either compromises tibial fixation of the ACL or migration of the posterior horn bone plug into the ACL tibial tunnel during terminal fixation. Thus, the most predictable posterior horn tunnel positions are either anterocentral or lateral to the ACL tibial tunnel. Because we can often use the same incision to fix both the ACL and posterior horn of the meniscus, we prefer the anterocentral location. The lateral location is uniformly effective, but requires an additional incision.

After establishing the posterior horn tibial tunnel, any hardware in the tibia or femur is removed as necessary and the residual ACL graft and over-the-top position are debrided. Excessive tunnel enlargement can be treated with modifications in the size of the BTB allograft bone block. The ACL tibial and femoral tunnels are then drilled in their proper locations. We typically will use the tunnels created during the primary ACL reconstruction if they are in good position. However, if a new tibial tunnel is drilled, we tend to place it more medially so that it remains as far from the more laterally placed posterior horn bone plug tunnel as possible. Following drilling of the tibial tunnel, the femoral tunnel is drilled. As previously mentioned, we typically try to maintain a 9-mm bone plug on the BTB allograft and drill a 9-mm tunnel while maintaining a 120-mm wide middle-third strip of patellar tendon (Fig. 4). Specific details regarding the steps required during the revision ACL are discussed elsewhere in this issue.

Next the meniscus is introduced into the joint and all steps of the meniscus transplant are completed prior to passing the ACL graft. For the bone plug technique, reducing the tibial spine and performing a modified low notchplasty between the fibers of the posterior cruciate ligament and the medial femoral condyle facilitate posterior plug passage. For the bone bridge technique, a 1-mm expansion of the slot relative to the bone bridge and meticulous debridement of residual soft tissue facilitates graft passage. A traction suture is placed at the junction of the posterior third of the meniscus and passed from inside-out using the appropriate zone-specific cannula through the contralateral portal. This traction suture is used to facilitate introduction and reduction of the meniscus and may be used as an additional fixation point if placed in an appropriate position relative to the capsule.

Once the meniscus is reduced anatomically under the femoral condyle, an inside-out meniscus repair is performed

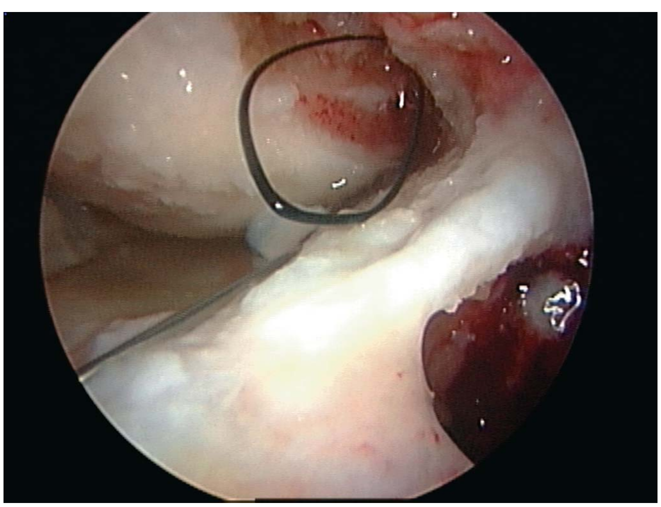

FIGURE 3. Arthroscopic view demonstrating the lack of tunnel communication between the tibial tunnel for the posterior horn of the medial meniscus and the ACL tibial tunnel. Note the suture loop of a suture passer exiting the tunnel of the medial meniscus posterior horn.

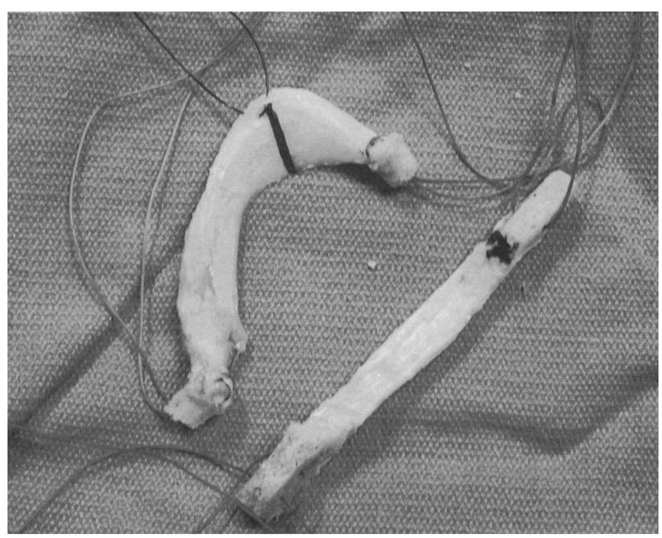

FIGURE 4. Final graft preparation demonstrating a BTB allograft with 9-mm width plugs while maintaining a 10-mm tendon width in an effort to minimize the tunnel diameter. The meniscus is prepared with an 8-mm posterior horn bone plug and a 9-mm anterior horn bone plug.

using several vertically placed 2-0 nonabsorbable mattress sutures beginning posterior and progressing anteriorly using standard inside-out meniscus repair techniques. The sutures are secured with the knee in complete extension and care is taken to tie the sutures beneath the iliotibial band or sartorius fascia to prevent tethering of the superficial layers. Direct arthroscopic visualization of the posterior horn is maintained to prevent distortion from excessive traction placed on the posterior horn bone plug sutures. The posterior bone plug is secured against the anterior tibia using a small nylon ligament button. The anterior horn bone plug is press-fit into a blind tunnel ideally reamed in the center of the footprint of the host anterior horn after the meniscus is secured posteriorly (Fig. 5). With the slot technique, the graft is fixed with a cortical bone interference screw or a sliver of bone taken from the allograft tibia used as a shim against the most central part of the graft (Fig. 6).

Finally, the ACL graft is passed. Beveling the leading edge of the bone block and placing traction sutures close to the apex of the leading edge to avoid eccentric pull will facilitate passing the ACL graft near a meniscal bone bridge or past bone plug tunnels. Alternatively, the use of a hamstring graft for the reconstruction of the ACL may facilitate graft passage past the bone bridge of the meniscal transplant. When a bone bridge is used on the medial side, it may be helpful to fix the bridge in the slot after ACL graft passage to avoid compromising the bone bridge during tibial tunnel reaming and graft passage.

Within the femoral ACL tunnel, the cortical edge of the ACL graft is oriented posteriorly, and the interference screw is placed anteriorly to minimize soft tissue injury. This also places the graft more posteriorly on the back wall of the femoral tunnel. After femoral fixation, the knee is cycled multiple times to assess femoral graft fixation and isometry. The tibial bone plug is rotated toward the lateral intercondylar wall, and the tibial interference screws are placed anteriorly on the cancellous surface of the bone plug. All tibial screws are secured with the knee in extension and slight axial load while applying firm tension to the sutures on the tibial plug. Graft position, tightness, and notch clearance are arthroscopically inspected in extension and flexion before closure. If a graft construct-tunnel mismatch is encountered, the tibial bone plug may be secured to the tibia with a staple.

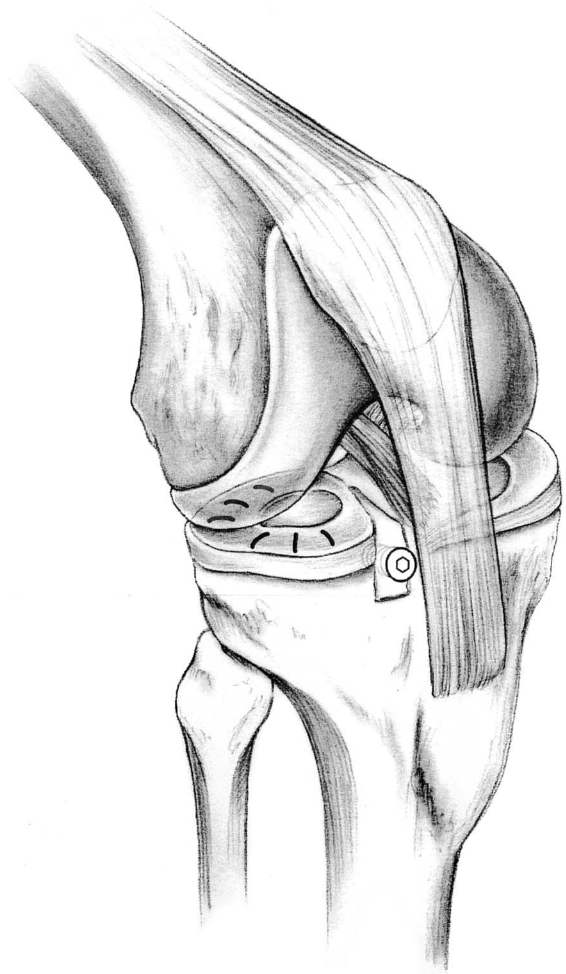

FIGURE 6. Schematic illustration demonstrating the bridge in slot technique with an allograft cortical screw used to transfix the bridge within the slot prior to meniscus repair.

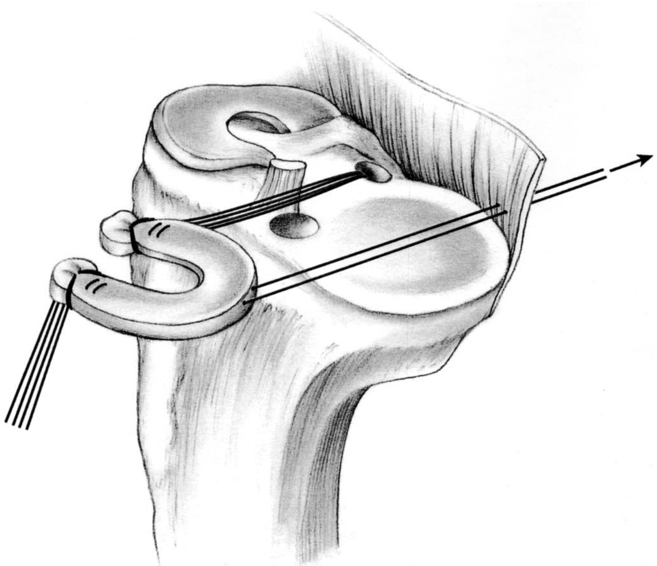

FIGURE 5. Schematic illustration demonstrating the bone plug technique. Note the blind tunnel anteriorly, which does not always require suture fixation if a press-fit is achieved. The posterior horn sutures are often fixed independent of the anterior horn sutures using a ligament button tied over the anterior tibia at the entrance of the tibial tunnel (not shown here). (Compliments of Cryolife, Kennesaw, GA).

REHABILITATION

Because of issues related to fixation, the rehabilitation following revision ACL reconstruction is often more conservative than the aggressive protocols used for primary ACL reconstruction. Patients who have received a meniscus transplant and a revision ACL reconstruction are placed under additional restrictions early in their rehabilitation. Patients must be counseled that adding a meniscus transplant to a revision ACL reconstruction increases the complexity of the case and the results are less predictable than primary ACL reconstruction. Patients must agree preoperatively not to exceed the limits placed on their knee postoperatively. Rehabilitation protocols are individualized and are based on the type of reconstruction, fixation strength, and other associated procedures that require special consideration.

For patients who have undergone a meniscus transplant and ACL revision, weightbearing is limited to no more than 50% body weight with the knee braced in full extension for 7 to 10 days. The brace is removed for therapy, early range of motion, quadriceps and hamstring isometrics, and hygiene. Occasionally additional limitations may be placed on a patient's weightbearing if fixation is less than optimal. After 2 weeks, they are slowly progressed to weightbearing as tolerated in a brace preventing flexion beyond 90° while weightbearing. Emphasis is placed on achieving full extension and quadriceps control. The patient is allowed to sleep without the brace providing full extension is achieved. Rotation of the tibial plateau on the femoral condyles is prevented to protect the meniscus transplant from shear stress. The brace is phased out at 6 weeks, and full weightbearing without crutch support encouraged by 8 weeks. At 3 months, the patient limits knee flexion to 90° while engaging in leg presses, and begins closed chain conditioning with full range of motion. At 4 months the patient may begin proprioception and more task-specific training limited by the patient's tolerance. Appropriate expectations and reasonable goals must be understood and agreed upon by both physician and patient.

RESULTS

There are a number of series of meniscus transplants published in the literature, but few focus on the combination of meniscus transplantation performed in combination with revision ACL reconstruction. The only published report of combined ACL reconstruction and meniscal transplants that

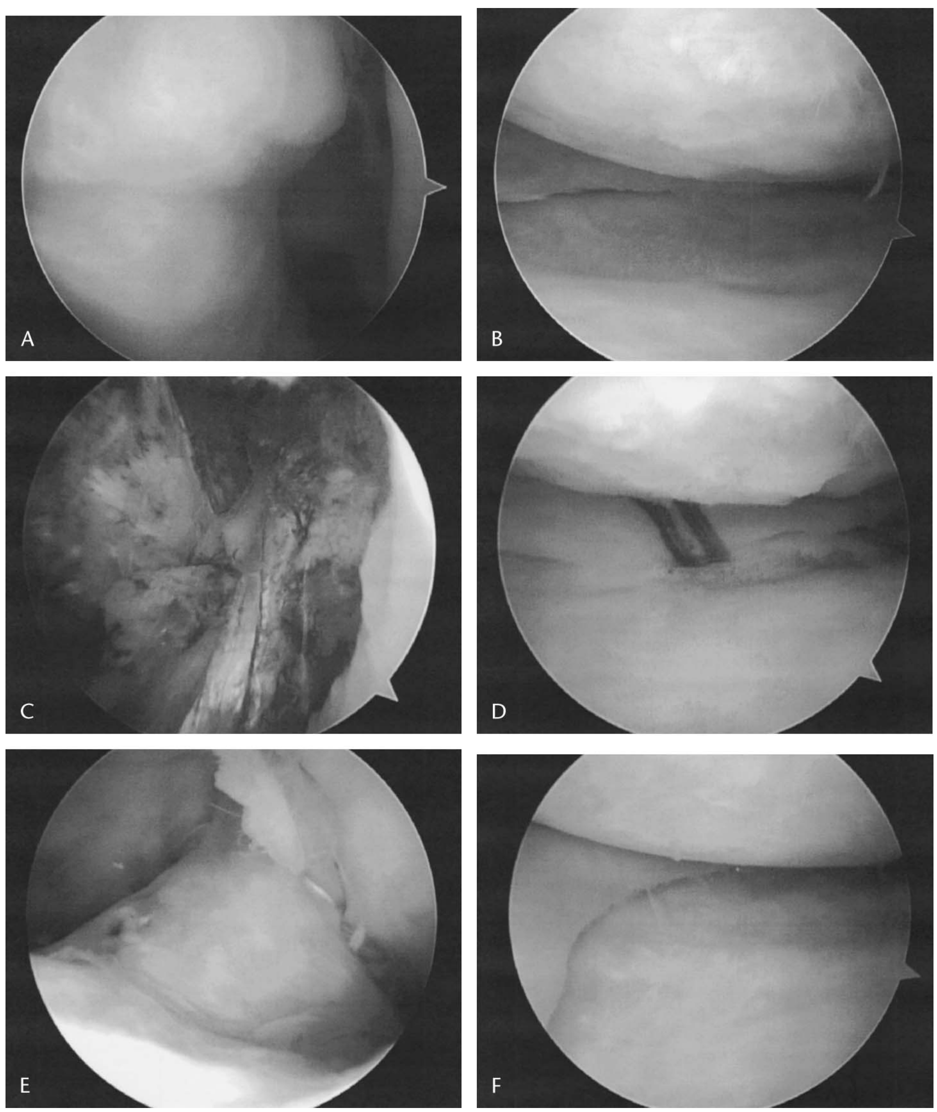

FIGURE 7. Case example of a 28-year-old man who underwent an ACL reconstruction with a BTB autograft and a complete medial menisectomy. He presented nearly 4 years later with the onset of significant instability and medial joint line pain. At revision surgery, he had (A) an empty lateral wall consistent with a failed ACL reconstruction, (B) an absent medial meniscus with late grade 2 cartilage damage on the medial femoral condyle. He underwent a (C) ACL revision with a BTB allograft and, (D) a medial meniscus transplant. At second-look arthroscopy nearly 18 months later, his (E) ACL and (F) medial meniscus were intact and there was no evidence of disease progression.

identifies a subset of patients undergoing revision ACL reconstruction is an uncontrolled retrospective review by Sekiya et al.[44] In that series, 28 patients who had ACL reconstruction and meniscal transplants were followed an average of 2.8 years (1.8 to 5.6 years). Within this group, 9 patients had a revision ACL reconstruction and primary meniscal transplant. With the exception of one patient who underwent a revision ACL and both medial and lateral meniscal transplant, all patients were rated as good or excellent by Lysholm and Knee Outcome Survey. There was a trend for lower scores in the revision ACL population compared with primary ACL reconstruction, a difference which is uniformly

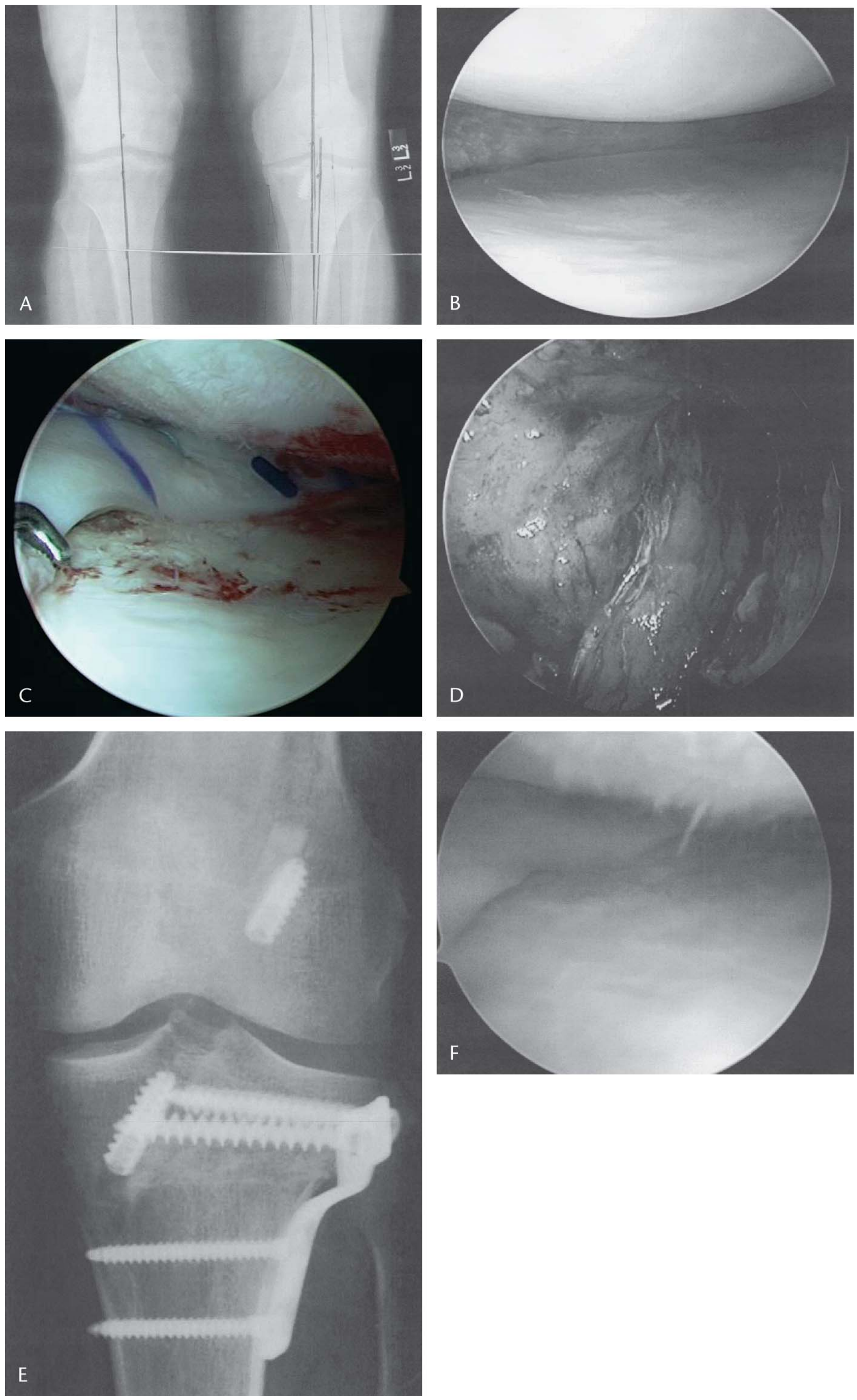

FIGURE 8. Case example of a 32-year-old man who underwent an ACL reconstruction with a BTB autograft and a complete medial meniscectomy. He presented nearly 5 years later with the onset of significant instability and medial joint line pain with a varus deformity. At revision surgery, he had (A) an anteroposterior weightbearing radiograph demonstrating varus alignment. At arthroscopy, he had (B) an absent medial meniscus with minimal articular cartilage damage along the posterior aspect of the medial femoral condyle and an attenuated ACL graft. He underwent (C) a medial meniscus transplant and (D) an ACL revision with a BTB allograft combined with (E) a closing wedge high tibial osteotomy. At 2 years postoperatively, a second look arthroscopy performed at the time of hardware removal demonstrated (F) excellent healing of his meniscus and ACL with no significant progression of his articular cartilage wear.

reported in several series of isolated revision ACL reconstruction.[45–48] Perhaps improved outcomes could be expected following ACL reconstruction if more patients received a meniscus transplant in conjunction with revision ACL reconstruction to re-establish a secondary restraint to anterior translation of the of the tibia.

Since 1997, the senior author (B.J.C) has performed 96 meniscus transplants, 17 of which were performed in combination with an ACL reconstruction. Seven of the transplants were performed with a primary ACL reconstruction (6 medial and 1 lateral) and 10 of the transplants were performed in combination with a revision ACL reconstruction (all medial). Nine of the ACL revisions were performed using a BTB allograft. Eight of the meniscus transplants were performed using the bone plug technique. Two were performed with the bone bridge in slot technique. Three patients failed within the 1st year due to recurrent instability (2 patients whose ACL grafts were being revised for the third time) or persistent pain despite arthroscopic evidence of complete healing of the meniscus and intact articular cartilage in a Worker's Compensation patient. Only the Worker's Compensation patient was revised to a partial knee replacement with complete resolution of his pain. The remaining 2 patients (one at 3 years and one at 6 years follow-up) have not undergone additional surgery, but continue to complain of some instability.

Of the remaining 7 patients, there were 3 women and 4 men with an average age of 27 years (range, 19–46 years) and an average follow-up of 12 months (range, 3–27 months). In all 7 patients, there were statistically significant improvements in the International Knee Documentation Committee, Lysholm, Tegner and SF-12 physical component scores. All patients stated that they were satisfied with their results and would undergo the surgery again given similar circumstances. Of the 7 patients, all denied complaints of instability and as a group, there was a mean reduction of pain of 50% as measured on a 10-point visual analogue scale compared with their preoperative pain scores.

CASE EXAMPLES

The first case is an example of the most common presentation whereby a 28-year-old male patient presented with a history of a prior ACL reconstruction using a BTB autograft and a complete medial menisectomy. The patient did well for approximately 4 years whereby he presented with recurrent instability during activities of daily living and medial joint line pain. His alignment was symmetrical and the mechanical axis was aligned with the center of the knee. He had a 2B Lachman and a 2+ pivot shift with medial joint line tenderness. He underwent a successful revision with a BTB allograft and a medial meniscus transplant using the double bone plug technique (Fig. 7).

The second case is an example seen when patients develop a varus deformity after a prolonged period of time following their menisectomy. A 32-year-old man underwent an ACL reconstruction with a BTB autograft and a complete medial menisectomy. He presented nearly 5 years later with the onset of significant instability and medial joint line pain with a varus deformity. He underwent a combined revision ACL reconstruction, medial meniscus transplant using the double bone plug technique and a simultaneously performed high tibial osteotomy (Fig. 8).

CONCLUSION

For select patients with a failed ACL reconstruction and a deficient or absent meniscus, a meniscus transplant combined with a revision ACL reconstruction will create a synergy wherein the meniscus provides improved physiologic load transmission and additional joint stability which protects the ACL reconstruction. In turn, a successfully revised ACL reconstruction will protect the meniscus transplant. Whether a bone-bridge or bone-plug method is selected, careful consideration must be given to the three-dimensional orientation of pre-existing or newly created tibial tunnels. Preoperative counseling is important to establish reasonable patient expectations of prolonged rehabilitation and the possibility of not returning to competitive athletic activity. In our experience, properly selected patients can expect the elimination of their instability complaints and significant reductions in ipsilateral joint pain with increased levels of function.

REFERENCES

1. Noyes FR, Barber-Westin SD. Revision anterior cruciate ligament reconstruction: Report of 11-year experience and results in 114 consecutive patients. *Instr Course Lect*. 2001;50:451–461.
2. Shelbourne KD, Gray T. Results of anterior cruciate ligament reconstruction based on meniscus and articular cartilage status at the time of surgery. Five- to fifteen-year evaluations. *Am J Sports Med*. 2000;28:446–452.
3. Levy IM, Torzilli PA, Warren RF. The effect of medial meniscectomy on anterior-posterior motion of the knee. *J Bone Joint Surg Am*. 1982;64:883–888.
4. Shoemaker SC, Markolf KL. The role of the meniscus in the anterior-posterior stability of the loaded anterior cruciate-deficient knee. Effects of partial versus total excision. *J Bone Joint Surg Am*. 1986;68:71–79.
5. Bourne RB, Finlay JB, Papadopoulos P, et al. The effect of medial meniscectomy on strain distribution in the proximal part of the tibia. *J Bone Joint Surg Am*. 1984;66:1431–1437.
6. Walker PS, Erkman MJ. The role of the menisci in force transmission across the knee. *Clin Orthop*. 1975;109:184–192.
7. Seedhom BB, Hargreaves DJ. Transmission of the load in the knee joint with special reference to the role of the menisci: Part II. Experimental results, discussions, and conclusions. *Eng Med Biol*. 1979;8:220–228.
8. Fithian DC, Kelly MA, Mow VC. Material properties and structure-function relationships in the menisci. *Clin Orthop*. 1990;252:19–31.
9. Alhalki MM, Hull ML, Howell SM. Contact mechanics of the medial tibial plateau after implantation of a medial meniscal allograft. A human cadaveric study. *Am J Sports Med*. 2000;28:370–376.
10. Paletta GA Jr, Manning T, Snell E, et al. The effect of allograft meniscal replacement on intraarticular contact area and pressures in the human knee. A biomechanical study. *Am J Sports Med*. 1997;25:692.
11. Szomor ZL, Martin TE, Bonar F, et al. The protective effects of meniscal transplantation on cartilage. An experimental study in sheep. *J Bone Joint Surg Am*. 2000;82:80–88.
12. Papageorgiou CD, Gil JE, Kanamori A, et al. The biomechanical interdependence between the anterior cruciate ligament replacement graft and the medial meniscus. *Am J Sports Med*. 2001;29:226–231.
13. Jager A, Welsch F, Braune C, et al. Ten year follow-up after single incision anterior cruciate ligament reconstruction using patellar tendon autograft. *Z Orthop Ihre Grenzgeb*. 2003;141:42–47.
14. Yoldas EA, Sekiya JK, Irrgang JJ, et al. Arthroscopically assisted meniscal allograft transplantation with and without combined anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2003;11:173–182.

15. Cole BJ, Carter TR, Rodeo SA. Allograft meniscal transplantation: background, techniques, and results. *Instr Course Lect*. 2003;52:383–396.
16. Levy IM, Torzilli PA, Gould JD, et al. The effect of lateral meniscectomy on motion of the knee. *J Bone Joint Surg Am*. 1989;71:401–406.
17. Barrack RL, Bruckner JD, Kneisl J, et al. The outcome of nonoperatively treated complete tears of the anterior cruciate ligament in active young adults. *Clin Orthop*. 1990;259:192–199.
18. Bonamo JJ, Fay C, Firestone T. The conservative treatment of the anterior cruciate deficient knee. *Am J Sports Med*. 1990;18:618–623.
19. Outerbridge RE. The etiology of chondromalacia patellae, 1961. *J Bone Joint Surg Br*. 1961;43:752–757.
20. Rosenberg TD, Paulos LE, Parker RD, et al. The forty-five degree posteroanterior flexion weight-bearing radiograph of the knee. *J Bone Joint Surg Am*. 1988;70:1479–1483.
21. Jackson DW, McDevitt CA, Simon TM, et al. Meniscal transplantation using fresh and cryopreserved allografts. An experimental study in goats. *Am J Sports Med*. 1992;20:644–656.
22. Buck BE, Resnick L, Shah SM, et al. Human immunodeficiency virus cultured from bone. Implications for transplantation. *Clin Orthop*. 1990; 251:249–253.
23. Shaffer B, Kennedy S, Klimkiewicz J, et al. Preoperative sizing of meniscal allografts in meniscus transplantation. *Am J Sports Med*. 2000; 28:524–533.
24. Pollard ME, Kang Q, Berg EE. Radiographic sizing for meniscal transplantation. *Arthroscopy.* 1995;11:684–687.
25. Farr J, Meneghini RM, Cole BJ. Allograft interference screw fixation in meniscus transplantation. *Arthroscopy.* 2004.
26. Cole BJ, Carter TR, Rodeo SA. Allograft meniscal transplantation: background, techniques, and results. In: Ferlic, DC, ed. *Instructional Course Lectures*. Rosemont, Illinois: American Academy of Orthopedic Surgeons; 2003:383–396.
27. Cole BJ, Rodeo S, Carter T. Allograft meniscus transplantation: indications, techniques, results. *J Bone Joint Surg Am*. 2002;84A:1236–1250.
28. Cole BJ, Fox JA, Lee SJ, et al. Bone bridge in slot technique for meniscal transplantation. *Op Tech Sports Med*. 2003;11:2, 144–155.
29. Fox JA, Lee SJ, Cole BJ. Bone plug technique for meniscal transplantation. *Op Tech Sports Med*. 2003;11:2, 161–169.
30. Farr J, Cole BJ. Meniscus transplantation: bone bridge in slot technique. *Op Tech Sports Med*. 2002;10:150–156.
31. Cole BJ, Noerdlinger M, Nho SJ, et al. Allograft meniscus transplantation: Background, techniques and results. *Orthopedic Special Edition*. 2002; 8:20–27.
32. Milachowski KA, Weismeier K, Wirth CJ. Homologous meniscus transplantation. Experimental and clinical results. *Int Orthop*. 1989;13:1–11.
33. Garrett JC. Meniscal transplantation. *Am J Knee Surg*. 1996;9:32–34.
34. Stollsteimer GT, Shelton WR, Dukes A, et al. Meniscal allograft transplantation: a 1- to 5-year follow-up of 22 patients. *Arthroscopy.* 2000; 16:343–347.
35. Chen MI, Branch TP, Hutton WC. Is it important to secure the horns during lateral meniscal transplantation? A cadaveric study. *Arthroscopy.* 1996;12:174–181.
36. Alhalki MM, Howell SM, Hull ML. How three methods for fixing a medial meniscal autograft affect tibial contact mechanics. *Am J Sports Med*. 1999;27:320–328.
37. Stone KR, Walgenbach AW. Meniscal allografting: The three-tunnel technique. *Arthroscopy.* 2003;19:426–430.
38. Maitra RS, Miller MD, Johnson DL. Meniscal reconstruction. Part I: indications, techniques, and graft considerations. *Am J Orthop*. 1999;28: 213–218.
39. Wilcox TR, Goble EM, Doucette SA. Goble technique of meniscus transplantation. *Am J Knee Surg*. 1996;9:37–42.
40. Shelton WR, Dukes AD. Meniscus replacement with bone anchors: a surgical technique. *Arthroscopy.* 1994;10:324–327.
41. Johnson DL, Swenson TM, Livesay GA, et al. Insertion-site anatomy of the human menisci: gross, arthroscopic, and topographical anatomy as a basis for meniscal transplantation. *Arthroscopy.* 1995;11:386–394.
42. Kohn D, Moreno B. Meniscus insertion anatomy as a basis for meniscus replacement: a morphological cadaveric study. *Arthroscopy.* 1995;11: 96–103.
43. Berlet GC, Fowler PJ. The anterior horn of the medical meniscus. An anatomic study of its insertion. *Am J Sports Med*. 1998;26:540–543.
44. Sekiya JK, Giffin JR, Irrgang JJ, et al. Clinical outcomes after combined meniscal allograft transplantation and anterior cruciate ligament reconstruction. *Am J Sports Med*. 2003;31:896–906.
45. Bach BR Jr. Revision anterior cruciate ligament surgery. *Arthroscopy.* 2003;19(suppl 1):14–29.
46. Johnson DL, Swenson TM, Irrgang JJ, et al. Revision anterior cruciate ligament surgery: experience from Pittsburgh. *Clin Orthop*. 1996;325: 100–109.
47. Uribe JW, Hechtman KS, Zvijac JE, et al. Revision anterior cruciate ligament surgery: experience from Miami. *Clin Orthop*. 1996;325: 91–99.
48. Wirth CJ, Kohn D. Revision anterior cruciate ligament surgery: experience from Germany. *Clin Orthop*. 1996;325:110–115.

