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Current Meniscal Allograft Transplantation

Jack Farr, MD, and Wayne Gersoff, MD†*

Abstract

Meniscal allograft transplantation is now gradually transforming from an interesting alternative in meniscal restoration algorithms to a reliable treatment of unicompartmental knee pain after meniscectomy. The past decade has allowed refinements in sizing, preservation, and fixation of the meniscal allograft. Current techniques focus on adherence to biomechanical principles in attempting to duplicate the force transfer of an intact meniscal tibial plateau construct. Although intermediate term outcome results are promising in regards to pain relief, the long term objective of articular cartilage preservation remains a goal.

Key Words: meniscus, meniscal transplantation, meniscal allograft

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INTRODUCTION

Meniscal pathology is one of the most common problems presenting to orthopedic surgeons. The treatment of meniscal injuries has evolved during the past 4 decades. No longer is the meniscus seen as an accessory structure that can be removed without consequence. The preservation of meniscal integrity and function has become the ultimate goal. Nevertheless, there remains a large pool of post meniscectomy patients—many of whom have symptoms. This pool consists of patients who underwent total meniscectomies in the past and, those in the present who, despite advances in meniscal repair techniques, have meniscal tears in which preservation of the meniscus structure and function is not possible. Post meniscectomy studies have shown that over time, many of the patients will ultimately experience some degree of knee deterioration.[1–11] There have been radiographic and clinical functional outcomes studies, which are now supported by MRI evidence showing that meniscal loss is a risk factor for progressive articular cartilage loss. The concept of meniscal transplantation has evolved as a surgical technique that attempts to restore as near normal as possible the structure and function of the knee joint.[12] At present, clinical science demonstrates the efficacy of meniscal transplantation in relieving pain, yet the ultimate goal to decrease the potential development of arthrosis in the affected compartments remains to be proven.

ANATOMY AND BIOMECHANICS

The anatomy and biomechanics of the meniscus have been well studied and documented in the literature.[13–15] Adherence to these principles is necessary to optimize the success of the procedure. The medial and lateral meniscus are fibrocartilaginous structures that are semilunar in shape and somewhat triangular in cross section. However, there are important differences between the medial and lateral menisci. Compared with the lateral menisci, the medial meniscus is longer in the anterior–posterior plane and thicker in the posterior horn. The medial meniscus has less excursion during flexion/extension secondary to its firm attachment to the deep fibers of the medial collateral ligament. It is critical to recognize that the medial meniscal horn attachments are at the anterior–posterior extremes of the tibial plateau. Its anterior horn attachment (which is more variable than the other 3 horns) is actually on the anterior slope or margin of the medial tibial plateau as opposed

From the *Cartilage Restoration Center of Indiana, Division of OrthoIndy, Indiana University School of Medicine, Indianapolis, Indiana; and †8671 South Quebec Street, Highlands Ranch, Colorado.

Reprints: Dr. Jack Farr, Clinical Associate Professor of Orthopaedic Surgery, Indiana University School of Medicine, Indianapolis, 5255 East Stop 11 Road, Suite 300, Indianapolis, Indiana 46237 (e-mail: indyknee@hotmail.com).

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to being on the superior aspect of the tibial plateau directly. Likewise, the posterior horn of the medial meniscus attaches to the posterior slope of the medial tibial plateau adjacent to the PCL attachment where both are on an inferiorly directed slope. These are critical anatomic points when transplanting the medial meniscus.

The lateral meniscus is more circular in shape and has its anterior and posterior horn attachment sites in closer approximation and unlike the medial meniscus, these horn attachments are in the plane of the tibial plateau. Due to the less firm capsular attachments, the lateral meniscus has more excursion during flexion or extension. Unique lateral meniscal considerations are the complex anatomy and attachments in the area of the popliteal hiatus. The lateral meniscus is minimally and variably attached in this area and further complicated by the variable attachments of the meniscofemoral ligaments of Humphrey and Wrisberg. These ligaments course from the posterior cruciate ligament to the posterior horn of the lateral meniscus in the area medial to the popliteal hiatus. Further stabilization of the lateral meniscus is provided by the posterosuperior and anteroinferior popliteal meniscal fasciculi. These attachments are not reproducible during lateral meniscal transplantation.

The biomechanical design of the meniscus is well suited for its functions. The meniscus is composed of a cellular component and an extra cellular matrix. The meniscal fibrochondrocytes exhibit different characteristics in different regions of the meniscus, depending upon their role. The cells are supported by a collagen framework composed of circumferential fibers linked by radially-oriented collagen fibers. This structural network helps to resist tension, compression, and shear. Together these 2 components allow the meniscus to perform its primary function of load transmission and shock absorbency that ultimately protect the articular cartilage.

SURGICAL TECHNIQUES

Indications or Contraindications

The most important indication for meniscal transplantation is for relief of pain localized to the meniscal-deficient compartment. Ideally, the patient should be in good health, with a stable knee, normal axial alignment, and grade 2 or less chondrosis. As the entire spectrum of cartilage and knee restoration continues to evolve, concomitant procedures to correct stability, malalignment, and chondral injury can be performed, as will be discussed later in this article. Age is a gray zone. Although 50 to 55 years of age is considered the upper chronological limit, physiologic age must also be taken into consideration. Active infection, inflammation arthritis, and crystal arthritis are contraindications. Additionally, a BMI of over 35 is considered a relative contraindication. The young patient who has undergone a subtotal or total meniscectomy secondary to an irreparable meniscus or discoid meniscus is of special concern. The long-term data on the success and ability of meniscal transplantation to protect the articular cartilage is not complete. However, the literature supports a prognosis for the development of articular cartilage degeneration, especially on the lateral side, in a meniscal-deficient knee. Although transplantation is performed only on symptomatic patients, in the young at risk patient, the threshold for transplantation may be lowered. This early intervention (before articular cartilage damage) may, in the future, be supported with biomarkers that currently are undergoing testing (volumetric MRI and genetic markers). At present, bent knee weight bearing radiographs (Rosenberg) and even bone scans may not be sensitive enough to predict or assess early and intermediate volumetric articular cartilage loss.

Soft Tissue Considerations

The meniscal allograft tissue should be obtained from a tissue-banking resource that is fully compliant with or exceeds all standards established by the American Associa-

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tion of Tissue Banks. At this time the best results are obtained by utilizing fresh-frozen or cryopreserved tissue.[16,17] It is essential that the meniscal allograft must be appropriately and accurately sized and be site specific. The most commonly accepted sizing method is described by Pollard.[18] The technique uses magnification corrected AP and lateral radiographs with direct measurements on the AP film for width and a multiplication factor to calculate the anterior–posterior length on the lateral film.

With the development of multiple all inside meniscal repair devices, there is a temptation to use these simpler techniques instead of inside out vertical mattress sutures for fixation of the meniscus. It must be realized that most of these devices are not designed for meniscal to capsular soft tissue repair, but rather meniscus-to-meniscus repair. In addition, their ultimate pull out strength has been demonstrated to be less than that of suture material using the time tested vertical mattress suture orientation. The use of these devices, at the time of this writing, is probably only indicated in the most posterior horn region in an effort to improve stabilization while minimizing the risk of neurovascular injury.

When performing a medial meniscal transplant the surgeon may face the challenge of a tight joint compartment. In this situation the intra-articular fibers of the medial collateral ligament can be partially released to facilitate opening of the joint space and accurate placement of the meniscus. This can be done superior or inferior to the meniscus. To optimize the smooth anatomic appearance of the rim for transplantation, it is often more rewarding to partially release (by step cut with sheathed blade, limited “pie crust”, technique or multiple punctures with a spinal needle) the MCL superior to the meniscus allowing the coronary ligaments to remain intact.

Regardless of the bone fixation technique, accurate reduction of the meniscal allograft is essential. During the procedure the reduction can be facilitated by the use of a pull-through suture placed at the junction of the posterior and middle third of the meniscus. It is important that this suture is passed from the inside to out and that it is placed at the appropriate position on the meniscal capsular junction. A mismatch between suture placement in the meniscus and capsular exit can make reduction extremely difficult.

Bone Plug Technique

The bone plug technique was the first bone-anchored technique used for medial meniscal transplantation.[19,20] It involved the creation of 2 bone plugs, either free hand or with coring reamers, at the anterior and posterior horn attachment sites. In the original concept, bony tunnels are then created in the host tibia corresponding to the anterior and posterior horn attachment sites. The technique is not indicated for lateral meniscal transplantation because the anterior and posterior horn attachments are in such close proximity that tibial tunnel communication could result with compromised fixation. Thus, bone plugs are used on the medial side as there is a greater distance between the anterior and posterior horn attachment sites. With this technique, passage of the bone plugs through the posterior tunnel can be difficult, and in difficult reductions the bone plug can fracture. In addition to appreciating the variability of the anterior horn attachment, it must be remembered that the anterior attachment site is usually on the anterior slope of the tibia. Therefore, the plug placement may be more of a press fit in a blind hole rather than a true tunnel. The attachment sites of the original meniscus are the guidelines for anatomic meniscal placement. Some authors discuss a compromised technique of allowing the anterior horn to be placed “where it fits best”. Although, this may make the procedure easier, it is nonanatomic and the underlying principle remains to duplicate the function of the meniscus as closely as possible. To further illustrate this problem, consider after the posterior plug is fixed that if first the meniscus is to be anatomically reduced anteriorly, then high

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levels of hoop forces must be translated throughout the meniscal rim. It would require superhuman effort to maintain these forces, create a receptacle area and then reduce and fix the plug in a manner that continues to maintain these hoop forces. Likewise, care must also be taken not to reduce the plug attachment too deeply in the obliquely-oriented posterior attachment site tunnel. This would result in a nonanatomic attachment site and thus not duplicate desired biomechanics. In either case, soft tissue fixation alone or 1 bone plug plus soft tissue fixation have been shown to not reestablish intraarticular contact areas.[21,22] In summary, the bone plug technique is an option for the medial compartment, and its success is largely dependent on attention to the anatomic details and maintaining hoop forces.

Bone Bridge Technique

The various techniques involving use of a bone bridge for meniscal transplantation are well described in the orthopedic literature.[23–27] The original articles should be consulted for the exacting details of each technique. Rather than paraphrase these articles, this section will seek to compare and contrast the different bridge techniques. The concept of fixing the meniscal allograft construct with a bridge of bone connecting the soft tissue horn attachments began with the keyhole technique. Since that technique, several other approaches to creating and inserting the bridge have evolved. In general, the bone bridge concept has theoretical advantages. Additive error from misplacement of horn insertions sites is avoided and fixation to re-establish hoop stress is secure. Bony fixation has proven superior over soft tissue fixation in the laboratory. With these positive attributes of bone fixation, the bridge was initially used for the lateral meniscus where the narrow distance between the horns made bone in tunnel fixation difficult. The bridge technique was also later expanded in some circumstances to the medial compartment.

Figure 1 depicts some of the different bone bridge types including: keyhole, slot, trough and dovetail techniques. Once the keyhole has been made, its dimensions are used to produce the key bridge. The fine-tuning of the key takes into account any mismatch between the keyhole and the slope of the plateau. This is technically very demanding. The dovetail and trough techniques have less demanding bridge shapes, whereas the slot technique allows a simple rectangular bridge to be preshaped independently of the slot (before the patient surgery begins).

Figure 2 illustrates the shape of the tibial recipient sites including keyhole, slot, trough, and dovetail. All those familiar with inserting an anterior cruciate ligament (ACL) reconstruction bone plug graft into a tunnel understand that even small mismatches can create frustration during insertion. Meniscal transplant bridge press-fit design, may require impaction, which may have the potential of creating fracture of the bone bridge or injury to the anterior horn attachment.

The goal of each bridge technique type is to allow placement of the horns as close to the anatomic horn sites as possible. If sizing is correct, then with anatomic horn placement, there is potential for the allograft to function in a manner similar to the natural meniscus. The medial-lateral position is determined by alignment of guides over the horn remnants. The superior-inferior position is selected by the surgeon using a guide, or in the case of the slot, the guide is fit in a superficial slot created in line with the slope of the compartment. Finally, the anterior–posterior position is obviously dependent on the original proper sizing of the allograft. If sizing is proper, then the surgeon selects the position with press fit techniques. With techniques that allow under sizing of the bridge, such as the slot technique, the position and fixation are separated. With the bridge in the channel, the knee is cycled near extension where there is minimal excursion of the meniscus. The concept is that of allowing the femoral condyle to capture the meniscus or tibial plateau construct, which is the desired end result (Fig. 3A). This allows the femoral condyle to fine-tune the position of the bridge at

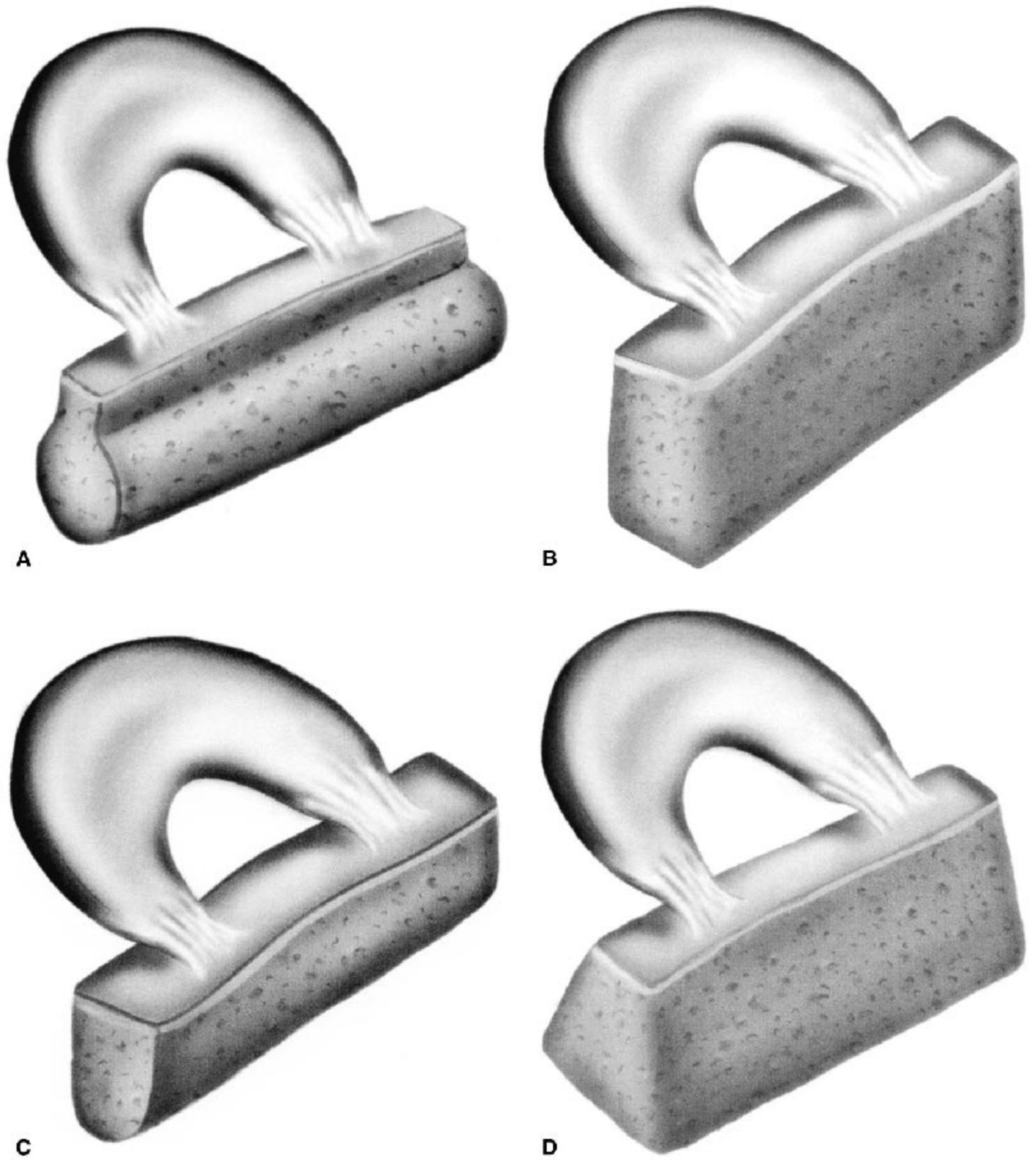

FIGURE 1. Illustrations of bone bridge shapes: (A) keyhole technique, (B) slot technique, C, trough technique, (D) dovetail technique.

which time the bridge is fixed by standards methods. Said another way, the natural tendency is for the surgeon to concentrate on how the meniscal transplant fits on the relatively flat tibial plateau whereas the biomechanical emphasis should be how the meniscal or tibial construct captures the femoral condyle and is thus able to transfer force over an optimal area. A few millimeters of error on the tibial side may have much less impact on contact surface area than a few millimeters error on not capturing the femoral condyle (see Fig. 3B).

Bridge fixation methods include: sutures through small tunnels took the horn sites, press fit, interference fit with screws bone pins (dowels), or bone graft. Following fixation of the bone bridge the soft tissue portion of the meniscus allograft is secured in standard fashion for all meniscal transplants with interrupted vertical mattress sutures using the inside out techniques supplemented

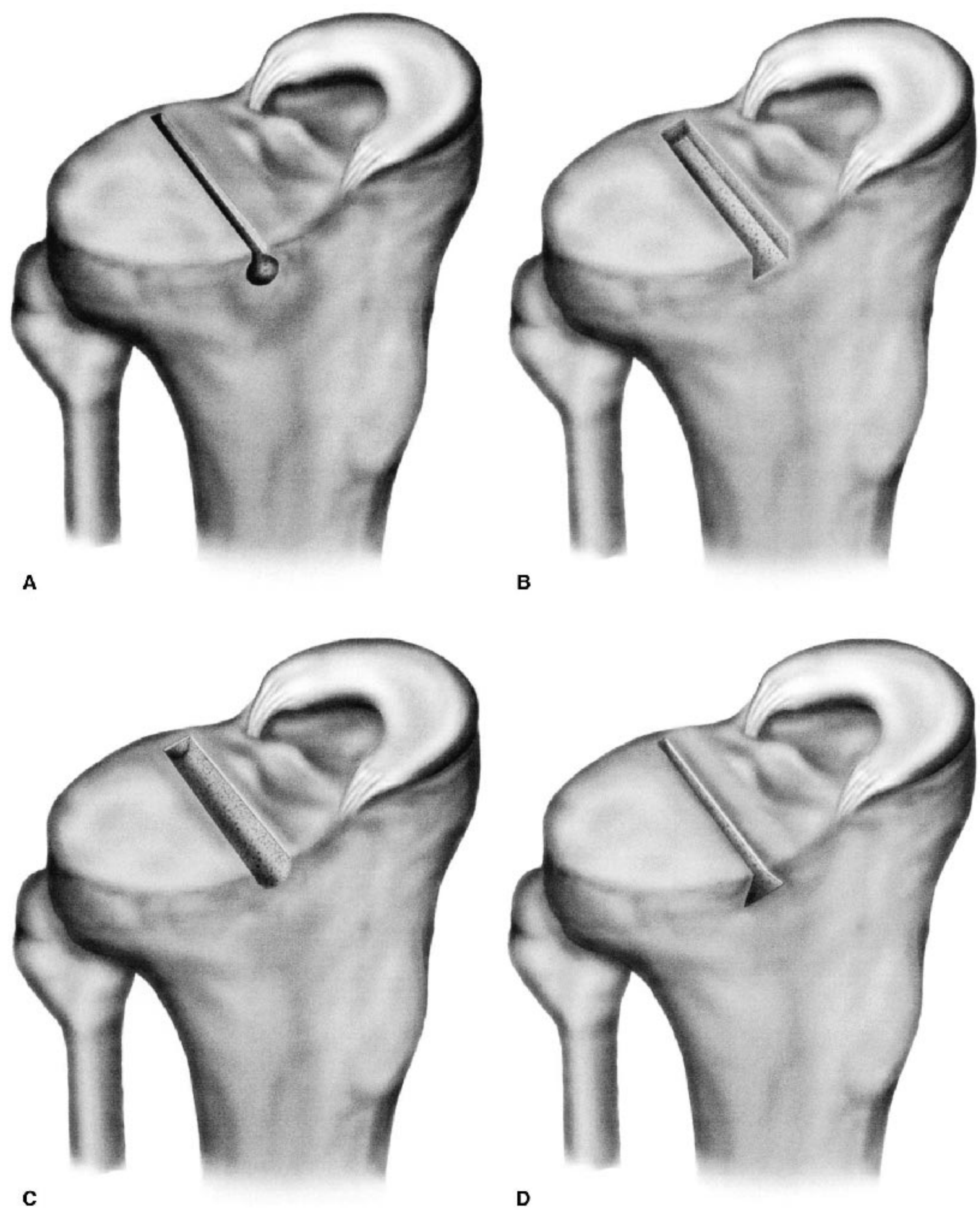

FIGURE 2. Illustrations of tibial recipient shapes: (A) keyhole, (B) slot, (C) trough, and (D) dovetail.

with all inside techniques as per surgeon preference.

RISKS AND COMPLICATIONS WITH MENISCAL TRANSPLANTATION

Some degree of risk is associated with all orthopedic procedures and a certain incidence of complications are unfortunately expected. Within this group of risks and complications, ultimate failure of the procedure is also included. The failure of the procedure points out the humbling fact that we are participating in a complex, multi-factorial biologic process that is incompletely understood. However, by analyzing the complica-

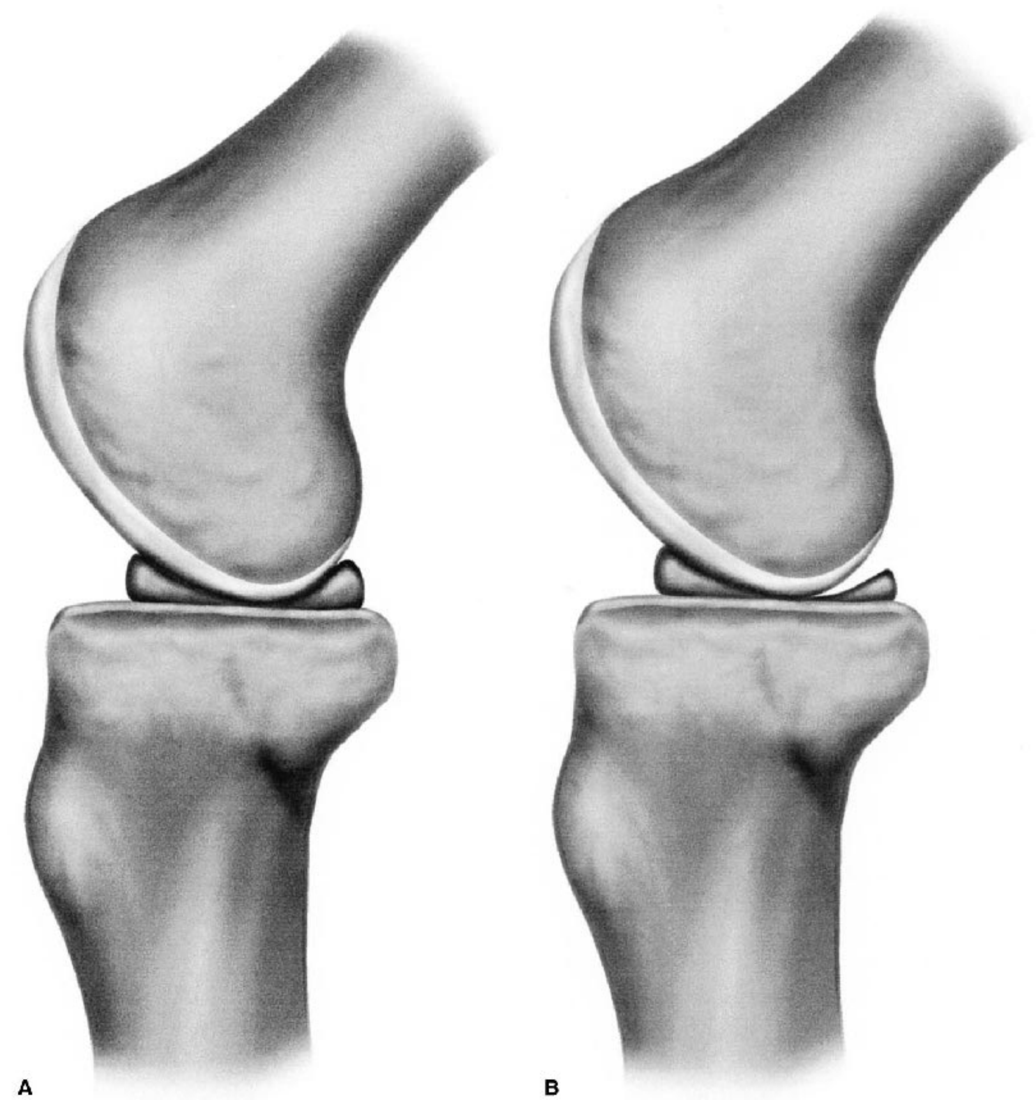

FIGURE 3. A, This meniscus is captured by the femoral condyle. B, Failure of meniscus to capture the femoral condyle.

tions that do occur, then a systematic approach may be developed in an attempt to minimize the number of complications and the resultant morbidity. Because they are multi-factorial, a better understanding of meniscal allograft transplantation complications may be possible by grouping the causes: intraoperative, early postoperative, and late postoperative.

Intraoperative complications may be decreased with preoperative planning and careful surgical technique. The graft is checked for sidedness and whether it is medial or lateral. If the wrong graft is present, the surgery is cancelled. Sizing mismatching can be minimized if the surgeon personally reviews the marker or sizing films and cross matches these with the tissue bank. On the other hand, subtle mismatches recognized intraoperatively may not be appreciated until reduction of the allograft. At that point, the surgeon must make the decision to cancel the transplant or make minor changes in the transplant horn position. The goal is to not create a “sub optimal solution” that is nonfunctional.

Whether bone bridge or bone plugs are formed, care must be taken not to remove or injure the meniscal attachment to the bone. If bone fixation is lost, the fixation is converted to less optimal soft tissue fixation. Another complication is having the transplant fall on the floor or other contaminated area. The ACL literature suggests Chlorhexidene or Betadine and copious pulsitile irrigation, which has worked for similarly contaminated ACL grafts.[28,29] Review of these articles may allow extrapolation to the meniscal allograft setting as per surgeon discretion. A plan for contamination prevention is advisable. Preventative measures include securing the traction suture early for control followed by placing the prepared graft in a specimen container with secure top. During preparation of the recipient site for placement of the graft care must be taken not to harm the articular surfaces anteriorly, and posteriorly the popliteal vessels should be protected by direct visualization of all bone and soft tissue work. During insertion of the graft adequate room for the soft tissue must be available so as not to injury the soft tissue. Insertion of the bone portion of the graft must be smooth and gentle, otherwise the bone bridge may fracture and require alternative fixation. Failure of the graft to be fully seated may cause impingement or non-anatomic positioning of the graft. Finally, when concomitant surgeries are performed, planning and rechecking are important. With HTO, propagation of the meniscal insertion site to the osteotomy is possible and with ACL reconstruction the ACL tunnel may intersect with the transplant system and interfere with fixation.

In the early postoperative period, generic complications include those associated with other arthroscopically assisted surgery and open joint surgery. Routine sterile technique and prophylactic antibiotics can minimize post operative infections to that associated with similarly invasive techniques such as allograft ACL reconstruction. It is important to know the tissue bank and the handling protocols in light of the reports of contaminated allografts highlighted by the Centers for Disease Control and the Food and Drug Administration in 2002. The decision on whether or not to retain the transplant at the time of early joint lavage for infection must be tempered with the total joint infection literature and type of organism. Certainly a Staph epidermitis infection originating from the surgical field is different from the Clostridia sordellii infection arising from a procurement error contaminated graft. Not specific to transplantation are deep vein thrombosis and pulmonary embolism.

Late complications may be related to the extensive nature of the surgery especially when concomitant procedures are performed. The healing response may cause degrees of arthrofibrosis, which are managed as per commonly accepted standards of debridement and gentle manipulation. The graft may tear in a standard "degenerative flap" manner, avulsion of the soft tissue from the bone fixation portion of the graft and from the very uncommon failure to heal at the periphery. Peripheral failure to heal is managed with local stimulation techniques and resuturing, whereas frank tears are debrided with the potential need for repeating the transplantation. Included with these late complications are the possibilities of viral transmission, prion transmission, or the potential of immunologic phenomenon. Although reports of frank acute rejection are rare and success versus failure has not been shown to correlate with the immune response, there remains the potential of subtle immunologic activity effecting repopulation of the allograft with host meniscal fibrochondrocytes and production/remodeling of a biomechanically effective extracellar matrix. Finally, current clinical evidence establishes the efficacy of meniscal transplantation for reducing or eliminating pain, but to be truly valuable the procedure must also protect the joint from articular cartilage degeneration. To avoid the complication of accelerating articular cartilage damage, it is important to pay particular attention to reestablishing as of the many functions of the natural meniscus as possible.

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REHABILITATION

Rehabilitation to date has been largely empiric. Past protocols have varied from full-unrestricted weight bearing and motion to very restricted weight bearing and motion.[30–34] As the meniscal transplantation technique matures, rehabilitation programs must still be respective of basic science principles as well as build upon clinical outcomes of previous meniscal transplant series. As in the past, these rehabilitation programs are also tempered with the experiences derived from meniscal repair and ACL reconstruction. The ultimate goal is the reestablishment of a fully functional pain-free knee with long term durability. A short-term result, which compromises the long-term protection of the articular cartilages, is not a success. To realize this goal, the entire knee must be addressed using early protected maintenance of strength and avoidance of arthrofibrosis. The articular cartilage needs early range of motion and some degree of loading to maintain optimal matrix composition.

Fortunately, there is usually a robust healing response of the soft tissue portion of the transplant in the red zone. Motion studies have demonstrated limited motion of the meniscus during the first 60° of flexion, and thus, this may be allowed immediately (weeks 0-2 flexion limited to 60°). As with ACL reconstruction, full symmetrical extension is maintained immediately with extension pillows or prone hangs. Most motion of the meniscus occurs after 90° of flexion and thus this is in the next range of flexion allowed with the goal of achieving 90° by 4 weeks (2–4 weeks flexion limited to 90°). The final phase of flexion is unrestricted (4 weeks and later), and near full flexion should be achieved by 6 to 8 weeks. During this entire postoperative period, each patient will have a unique course and often cannot be pigeon holed into this "cook book" approach. This is based on the differences underlying the healing response, repopulation and remodeling. Although it is impossible at present to titrate the rehabilitation and function by the extent of matrix remodeling (future MRI/PET scan techniques may allow this approach), it is possible to monitor patellar mobility and the general appearance of soft tissues. If a more extensive fibrosis response is noted, the guidelines for scar management and range of motion may be accelerated.

Weight-bearing recommendations are likewise empiric. On one hand, there are concerns that too much loading too early may allow plastic deformation of the meniscus, which has few cells to maintain a healthy matrix. On the other hand, there is the general appreciation that the knee and particularly the articular cartilage, requires some degree of loading for optimal health. Once the meniscus has metabolically active cells and remodeling is occurring, certain loading is necessary to guide this remodeling in keeping with the underlying principle of Wolfe's Law. Keeping these basic science considerations in mind, patients' activities should be modulated based on the results of rehabilitation techniques related to meniscal transplantation to date. Thus, at present, minimal weight bearing is allowed during the first 4 weeks, followed by progression to full weight bearing as tolerated. During this transition, it is important that a normal gait is maintained and that quadriceps weakness and pain do not create a flexed knee gait.

Standard strengthening, proprioceptive, and functional training are then added to an ACL type of reconstruction rehabilitation program, but with avoidance of squatting. Patients should be counseled preoperatively that this is a salvage procedure with the first goal being to alleviate pain. If all goals of strength, range of motion, and pain relief are met, then activities may be advanced using a functional progression approach from running to unrestricted activities. Realistically, this takes most patients more than 6 months.

RESULTS

The first published report of an isolated meniscal transplant was by Milachowski[35] in 1989. Since that time multiple series have been reported. There are different variables in each study such as: patient population, knee arthrosis, graft presentation, surgical techniques, additional surgical procedures, rehabilitation, and outcome measurement parameters. As a result, it becomes difficult to make accurate and universally accepted conclusions regarding the results of meniscal transplantation. Milachowski's publication in 1989 on 22 patients with an average 14-month follow-up demonstrated healing of 15 of 18 grafts peripherally by arthroscopic evaluation. Milachowski had used both fresh-frozen and freeze-dried grafts, with the fresh-frozen appearing more normal microscopically.

In 1993, Garrett[36] reported the 2- to 7-year follow-up of 43 patients. His patient population included complex cases, some of which were salvage-type patients. Only 6 patients had isolated meniscal transplantation, with 28 patients undergoing second-look arthroscopies. Twenty of these patients demonstrated healing of the meniscal allograft. The 8 failures in this group were attributed to grade 4 arthrosis. The remaining 15 patients were asymptomatic and considered to have a good clinical outcome.

Noyes[37] evaluated a large series of patients in 1995. This series reviewed 96 fresh-frozen-irradiated grafts in 82 patients. In retrospect, it is understandable that the results were extremely poor. Of the 96 implants, 58% failed completely, 31% were partially healed, and 9% healed. Twenty-nine of the menisci had to be removed less than 2 years after surgery. No transplant was done with both anterior and posterior bone plug attachment sites. The presence of grade 4 chondrosis was associated with a 50% failure rate. The honest reporting of Noyes, highlighted problems with earlier approaches. Cameron and Saha[38] reported their results on 67 irradiated menisci without bone anchors in patients with generally advanced unicompartmental arthritis. It should be noted that these patients also underwent osteotomy to unload that compartment at the time of surgery. This emphasizes the multi-factorial nature of knee problems making comparison of studies in the literature often impossible. Nevertheless, 87% of these patients demonstrated good or excellent results at a mean average of 31 months of follow-up. Van Arkel, and DeBoer reported on 23 patients with a minimum of 2-year follow-up who underwent isolated meniscal transplantation.[39] Twenty of the patients were felt to have a satisfactory result with 3 failures at less than 24 months, possibly likely related to uncorrected malalignment.

Stollsteimer[40] reported a series of 22 patients with 23 cryopreserved allografts. Implantation was done arthroscopically assisted with bone plugs. The patients were followed for an average of 40 months. While the majority of patients noted a reduction in pain and did not experience an adverse outcome, the allografts demonstrated 37% shrinkage on MRI studies. In 1999 Carter[41] reported on 46 transplantations with a minimum 2-year follow-up. Thirty-eight of the patients underwent arthroscopic second looks between 3 and 48 months, with most occurring in the range of 6 months. Four patients were considered failures, 4 had visible shrinkage, and 2 showed signs of progression of arthritis. It should be noted that 32 of the 38 patients reported pain relief and improvement in activities. Cole and Harner[42] reported in 1999 the results of 22 fresh-frozen menisci. Eighty-eight percent of the patients reported improvement in pain with associated improvement in knee function. Rodeo[43] has reported on a comprehensive review of the literature. As of March 2001, he reported on a total of 1599 meniscal transplants in 1551 patients. Direct objective evaluation of the transplanted tissue either by radiographic study or arthroscopy was done in 366 of the menisci in 338 patients. This series included fresh, fresh-frozen, cryopreserved, freeze-dried, irradiated, and non-irradiated menisci. The menisci were implanted both with and without bone plugs. Concomitant procedures were performed in all but 136 cases. There was no consistent rehabilitation noted from one study to another. The co-author's (Wayne K.

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Gersoff) personal experience began in 1991. Currently 80 meniscal transplants have been done in 78 patients. During the time of this series there have been subtle changes in the surgical technique, rehabilitation, and understanding and incorporation of the associated basic science. Of these 80 patients, 28 had undergone concomitant procedures consisting of ACL reconstruction, autologous chondrocyte implantation, or tibial osteotomy. Fifty patients have been followed for more than 2 years. Forty of these patients can be considered to have a good or excellent result with improvement in pain and function. The 8 failures, 6 of which were longer than 5 years post implantation, were noted to have pre-existing grade 4 arthritic changes or uncorrected malalignment. These were also performed early in the series before these factors were known to be deleterious to the outcome of meniscal transplantation.

CONCOMITANT PROCEDURES

Ligamentous Reconstruction

Ligamentous instability of the knee must be corrected either prior to or at the time of meniscal transplantation. If uncorrected, the meniscal allograft will be subjected to abnormal biomechanical forces that will ultimately result in either failure or damage. While the ACL is the most common ligament requiring reconstruction at the time of meniscal transplant, this same treatment philosophy applies to the posterior cruciate ligament, collateral ligament, or posterolateral corner. These procedures can be done as a single-stage procedure. Depending upon the technique chosen for meniscal transplantation, the tibial tunnel placement for ACL reconstruction will only be minimally altered. If a bone bridge technique is used, any intersection between the tibial bone slot and tibial ligament tunnel can be easily accommodated. This is accomplished by pushing the ACL graft to one side of the tunnel while reducing the bone bridge of the meniscal allograft.

Chondral Defects

The presence of a grade 3-to 4-chondral defect has been considered a contraindication for meniscal transplantation. However, with the increasing reports of success with osteochondral grafting or autologous chondrocyte implantation the number of treatable patients can be expanded. It is important to select the appropriate articular cartilage restoration procedure based on the guidelines established for size and location.

Meniscal transplantation and articular cartilage restoration is best done as a single-stage procedure. This minimizes the potential for damage to either the cartilage repair or meniscal allograft. In performing the combined procedure, the meniscus should be reduced and fixed prior to osteochondral plug placement or periosteal fixation. This will minimize damage to the graft or periosteum during reduction and suturing of the meniscal allograft. The results of combined meniscal transplantation and autologous chondrocyte implantation are encouraging. Twenty-two patients with an average of 28 months follow-up underwent this combined procedure as reported by Gersoff.[44] These patients demonstrated improvement in the Cincinnati knee rating scale from 2.4 preoperatively to 7.6 postoperatively, with 2 poor results.

HTO Techniques

It is not uncommon for patients with varus knee alignment to become symptomatic after medial meniscectomy and those with valgus alignment to be become symptomatic after lateral meniscectomy. In the past, these patients with intact articular surfaces would be managed with osteotomy alone. However, the problem of pain is not solely a result of malalignment, because the contralateral knee usually has the same malalignment and is asymptomatic. Therefore, the logic of realignment is to address the underlying malalignment pathology and its contribution to compartment overload pain and to protect the transplanted tissues from overload, especially during the re-population and remodeling phases. This optimization of joint forces is common to all cartilage restoration techniques. When optimizing forces in the compartment being transplanted, even small amounts of mal-alignment are addressed (eg, 3° varus, which would not typically be considered for realignment by an isolated osteotomy). In light of the marked forces often needed to open the compartment for suture placement, the meniscal transplant is completed before the osteotomy. No special modifications are necessary for a distal femoral varus osteotomy, yet many of the valgus malalignments are less than 10° of valgus and can be treated with a high tibial varus osteotomy, if joint line obliquity is not a problem. When combining meniscal transplantation with tibial osteotomies, it is important to plan the cuts as distally as possible and then follow the cuts under fluoroscopy. If there is concern that there will be crack propagation, prophylactic compression screws can be placed just inferior to the transplant prior to making the osteotomy. Rehabilitation is a combination of the more conservative aspects of both procedures. With this in mind, it remains humbling to realize the goal of improving joint force through osteotomy is largely empiric because gait forces will ultimately decide compartment loading.

Patellofemoral

Patellar pain is not uncommon in patients being evaluated for meniscal transplantation. The most common reason is a decrease in lower extremity muscle strength and balance, which is treated with standard rehabilitation. On the other hand, certain common patello-femoral problems can be seen in these patients and should be managed as per established guidelines. The concern in the meniscal transplantation patient is when there is pain associated with a chondral lesion that is mechanically addressable through tibial tubercle medialization or anteromedialization. When indicated for standard patellofemoral treatment, the surgery for the patellofemoral joint may be performed at the same setting. Two considerations must be kept in mind: the proximal cuts for the tubercle must be well controlled to avoid propagation into the bone plugs or bone bridge regions of the meniscal transplant. Rehabilitation must take into account the delicate and complex nature of patellofemoral pain.

CONCLUSION

Although the basic concept of meniscal transplantation is similar to that originated in 1984, both new basic and clinical science information has allowed continuous improvement regarding our understanding, application, and performance of the surgical procedure. During the initial, early stages of meniscal transplantation, basic science knowledge was slowly evolving. There was uncertainty regarding many of the current nuances. For example, choosing the best graft preservation technique—fresh-frozen, freeze-dried, fresh, or cryopreserved. Even basic techniques such as the surgical approach have changed from a large arthrotomy and sometimes even open release of the medial collateral ligament to an arthroscopically assisted approach. The understanding of the important concomitant role of alignment, ligamentous stability, and articular cartilage repair was also evolving. Although the results of these early meniscal transplant patients were promising, certainly the longer-term results were less encouraging.

Following this early phase, several specific meniscal transplantation surgical instrumentation systems were developed. Improved arthroscopic instrumentation meant less open and less invasive surgery. Interpretation of early failures resulted in selecting more favorable graft preservation and fixation techniques. Because the process of meniscal allograft healing became better understood, the rehabilitation process was advanced and refined. Meniscal transplant surgeons also became more cognizant of the importance of treating associated ligamentous instability and malalignment, but the treatment of articular cartilage defects was still an unanswered challenge.

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The present state of meniscal transplantation allows a reproducible reconstruction of the meniscal-deficient knee, but further development is necessary. Present indications, techniques, and graft selection are based on the results of earlier ground breaking studies. Certain principles have achieved somewhat uniform acceptance: the graft should be cryopreserved or fresh-frozen and the procedure should be performed with the use of bone fixation, both anteriorly and posteriorly. Surgical guide systems based on anatomic and biomechanical considerations are available and have the potential to provide more reproducible results. Not only can the meniscal transplant surgeon address ligamentous instability and malalignment successfully, but also restoration of articular cartilage damage is now part of the knee restoration armamentarium . There will continue to be improvement in the guidelines for the rehabilitation of meniscal transplantation patients based on healing and remodeling. In this current era, it is anticipated that patients treated using of today's meniscal transplantation algorithm will have even better results than those of the early 1990s. Nevertheless, as with early design changes in total joint arthroplasty, we must remain humble until actual long-term data are analyzed.

The future of meniscal transplantation will be exciting. Biomechanics and tissue engineering will further establish the role of basic science in the clinical realm. Manipulation of growth factors into the local environment (directly, indirectly, or through gene therapy) may aid in the repopulation, growth, and remodeling phases of healing. These same principles will potentially also decrease the numbers of meniscal-deficient knees as meniscal healing and fixation techniques continue to improve preservation rates. Finally, meniscal transplantation will probably be supplanted with tissue engineered scaffolds allowing rapid repopulation by host cells. Advanced techniques such as these, along with standard meniscal transplantation will assume a larger role in the armamentarium of the knee restoration surgeon.

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