Surgical Options for Meniscal Replacement

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Abstract

As a result of biologic issues and technical limitations, repair of the meniscus is indicated for unstable, peripheral vertical tears; most other types of meniscal tears that are degenerative, significantly traumatized, and/or located in an avascular area of the meniscus are managed with partial meniscectomy. Options to restore the meniscus range from allograft transplantation to the use of synthetic technologies. Recent studies demonstrate good long-term outcomes from meniscal allograft transplantation, although the indications and techniques continue to evolve and the long-term chondroprotective potential has yet to be determined. Several synthetic implants, none of which has US Food and Drug Administration approval, have shown some promise for replacing part or all of the meniscus, including the collagen meniscal implant, hydrogels, and polymer scaffolds.

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J Am Acad Orthop Surg 2012;20: 265-272

http://dx.doi.org/10.5435/JAAOS-20-05-265

The meniscus plays a vital role in protecting the health and function of the knee joint. Meniscal tears are common; management is reserved for symptomatic tears. When nonsurgical treatment fails to address symptoms, surgery is indicated.

Primary surgical options include partial meniscectomy or meniscal repair. Because of biologic and technical issues, meniscal repair is typically limited to unstable, vertical, peripheral tears; therefore, most meniscal surgeries are partial meniscectomies.[1] Each year, 690,000 partial meniscectomies and approximately 1 million additional knee arthroscopies (most of which involve at least some débridement of the meniscus) are performed in the United States.[2] Surgeons who perform these procedures should attempt to preserve as much intact meniscal tissue as possible because altered biomechanics following partial meniscectomy increase articular cartilage contact pressures and can hasten joint degeneration.[1,3,4]

Several options exist for restoring the deficient meniscus, from allograft transplantation to synthetic technologies. Recent studies have demonstrated good short-term outcomes from meniscal allograft transplantation, although the indications and techniques are evolving. Despite the improvement in clinical symptoms, however, the long-term chondroprotective potential of meniscal transplantation has yet to be determined. Several synthetic implants have been developed to replace part of or the entire meniscus, including the collagen meniscal implant, hydrogels, and polymer scaffolds. These devices have shown some promise in recent studies, although clinical experience with their use is limited.

Meniscal Transplantation

Meniscal transplantation has become an accepted management option for

Table 1

Contraindications to Meniscal Transplantation

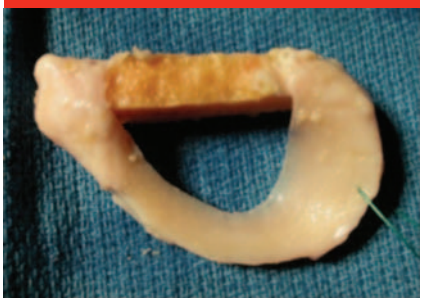
Age >50 years; skeletal immaturity
Diffuse advanced chondral degeneration (ie, grade IV)
Flattening of the involved condyle or significant osteophytes
Knee extension loss >5° compared with the contralateral limb or knee flexion <125°
Inflammatory arthritis or synovial disease
Unaddressed cruciate insufficiency
Unaddressed skeletal malalignment
Obesity (body mass index >35)

selected symptomatic patients who have undergone a complete or near-complete meniscectomy. The primary indication for a meniscal transplant is pain localized to the involved compartment. So-called prophylactic transplantation in young, athletic, asymptomatic patients is not indicated because significant potential complications are associated with the procedure. In addition, evidence is lacking that meniscal transplantation definitively prevents long-term arthrosis.

Patient age of <50 years is the accepted upper limit for meniscal transplantation; however, no lower age limit has been established other than skeletal maturity. To date, no studies have been published evaluating age as it affects outcome. At the time of transplantation, there should be only mild preexisting arthrosis and no focal lesion higher than grade III by the International Knee Documentation Committee (IKDC) classification.[5] Any focal cartilage lesions should be addressed either before or concurrent with the transplantation. Contraindications to meniscal transplantation may relate to the knee and overall patient health (Table 1).

A review of existing clinical trials consistently confirms that several

Figure 1



Photograph of a meniscal allograft.

management principles should be mandatory for surgeons performing this procedure. These principles include the reestablishment (if necessary) of normal knee alignment and stability; the implantation of a size-matched, nonirradiated graft with secure fixation of the meniscal horns (Figure 1); and a return to only light sports activities to optimize the chances for graft survival.

Several factors at least theoretically influence clinical outcome following transplantation. These can be categorized into knee-specific factors (ie, chondral damage, ligamentous stability, axial alignment, prior surgery), graft-specific factors (ie, medial versus lateral side, method of preservation, secondary sterilization, sizing method), surgeon-specific factors (ie, surgeon experience, insertion method, graft fixation, concomitant procedures), and rehabilitation-specific factors (ie, range of motion, weight bearing, continuous passive motion, return to activities).

Accurate sizing of the allograft is likely the most critical technical factor affecting clinical success. Knee joint tolerance to size mismatch is not completely understood, although estimates suggest that a size tolerance of 5% is acceptable. However, to date, no study has evaluated size tolerance as an outcome measure. Not definitively answered is the question of who is responsible for accurate size calculation, the tissue bank or the surgeon. Shaffer et al[6] found that MRI was slightly more accurate than plain radiography in determining accurate sizing. However, measurement accuracy within 2 mm was found in only 35% of their specimens.

Historically, most meniscal transplants have been harvested in an aseptic fashion and then processed as either prolonged fresh grafts (4°C), deep-frozen grafts (–80°C), lyophilized grafts (freeze-dried), or cryopreserved grafts (ie, slow-freezing the graft to –196°C in an anhydrous environment to prevent intracellular water crystallization). Initially it was assumed that preservation methods that maintain cell viability (ie, fresh and cryopreserved) would enhance graft function. However, basic science data in animal models[7,8] have shown a relatively rapid repopulation of donor DNA with recipient DNA, thereby raising questions about the necessity of cell viability—and its inherent cost—on graft survival and, consequently, on clinical outcome. As a result, most surgeons use either prolonged fresh or deep-frozen grafts.

Meniscal allografts are associated with the potential for transmission of not only bacterial organisms but also viral and fungal pathogens. Because the transplanted tissue has the potential to transmit bacterial, fungal, and viral infection (including hepatitis and the human immunodeficiency virus [HIV]), graft sterilization has been used as a means of reducing this risk. Although gamma radiation has been used as a common method of secondary sterilization of allograft tissues, the data are limited in regard to the effect of gamma radiation on meniscal allografts. Gamma radiation at dosages 1.0 to 1.5 Mrad (10,000 to 15,000 Gy) has been shown to inactivate large classes of these microorganisms.[9,10] Concern regarding the effect of irradiation on the mechanical function of the me-

niscus[11] has led to a diminished clinical use of any form of meniscal allograft irradiation because doses higher than those typically used (ie, 1.5 to 2.0 Mrad) are needed to eradicate HIV.[12] A critical review of the existing literature makes it difficult to formulate conclusions as to the necessity of secondary sterilization.

Although there is no ideal method of meniscal allograft fixation, commonly accepted principles include the use of strong sutures placed in a vertical-mattress fashion, tied over the joint capsule, with accurate reestablishment of the native meniscal horn insertions. Ideally, some peripheral rim tissue should be left to decrease peripheral extrusion of the implant and to provide firm tissue through which to pass the fixation sutures. Success rates with early efforts at meniscal transplantation were likely hampered by the failure to attach either one or both of the meniscal horns to their original locations. The greatest area of innovation and advancement has been in terms of securing these horns so as to preserve the so-called hoop stress of the normal meniscus. Basic science data have confirmed the importance of horn fixation to prevent extrusion of the meniscus with weight bearing.[13-15]

It is unclear from the available data whether there is any difference between bony fixation or soft-tissue fixation of the meniscal horns (assuming secure fixation with either method). Methods that have been used include the use of bone tunnels (for either bone plug or soft-tissue fixation) and a variety of bone-bridge techniques (eg, Keyhole [Arthrex, Naples, FL], Dovetail [Arthrex]) that leave the anterior and posterior horns attached to the meniscal cartilage and to each other. The bone-bridge methods are optimal for lateral meniscal transplants because the lateral meniscal horns are approximately 1 cm apart. A bone-bridge construct is contraindicated for medial meniscal transplantation with associated anterior cruciate ligament reconstruction because of the proximity of the two grafts. To date, there have been no comparative trials demonstrating one method of fixation to be superior to another.

Recommended methods of rehabilitation following meniscal transplantation vary in the published literature. Patellar mobilization, therapeutic modalities, and quadriceps/hamstring strengthening are initiated immediately postoperatively. Bracing is often recommended for the first 6 weeks to allow protected range of motion (except deep flexion) so as to enhance the biologic milieu of the healing transplant. Despite a lack of supportive data, limited weight bearing has been recommended while the transplanted meniscus heals to the periphery. Most patients are able to bear full weight on the involved limb by 8 weeks. Jogging is allowed at 3 to 4 months, with progression to running, cutting, and sports-specific activities at 4 to 6 months, as tolerated.

A low-grade effusion is often seen for the first year following transplantation and may necessitate a slower rehabilitation regimen. Meniscal transplantation is not analogous to a large meniscal repair, in which return to high-level sports is a realistic goal. Based on the available literature, it is not possible to determine the ideal progression of weight bearing or the influence of knee motion on allograft healing and biomechanics. Until such studies are performed, return to strenuous sports cannot be recommended after meniscal transplantation.

In general, published data regarding outcomes following transplantation are limited by the absence of control groups, the evaluation of mixed patient populations, inconsistent or nonexistent exclusion criteria for transplantation, and variability in the use of validated outcome measures.[5] Nevertheless, a growing body of literature provides short- to long-term results of meniscal transplantation (Table 2).

The success of the procedure may be highly dependent on the side of involvement; Verdonk and colleagues[25,28] found a 72% success rate for medial meniscal allografts but a 63% success rate for lateral grafts. However, Cole et al[26] found that patient satisfaction was 93% for lateral meniscal transplants but only 68% for medial transplants.

Ultimately, the long-term effect of meniscal transplantation on the radiographic progression of osteoarthritis remains to be determined. An increase in the degree of osteoarthritis was seen in 42% of patients in a recent systematic review.[5] MRI has been used to provide a more objective evaluation of the transplanted graft; Potter et al[36] reported meniscal degeneration in 63% of patients. All patients in their series with graft extrusion were symptomatic. In addition, all patients with meniscal degeneration on MRI reported pain but no locking, whereas all patients with meniscal fragmentation reported both pain and locking. In a similar study, Lee et al[37] compared the clinical outcome of extruded and nonextruded meniscal allografts. They reported a mean extrusion of 3 mm but no effect of meniscal extrusion on knee function. The degree of meniscal extrusion remained stable after 1 year.

Second-look arthroscopy has been performed in several studies[17,19,20,24] to define more accurately the status of the transplant as well as the adjacent articular cartilage. However, the arthroscopic assessment of a meniscal allograft cannot be used to determine its histologic architecture, cellular repopulation, or vascular supply because the gross inspection of the

Table 2

Published Success Rates Following Meniscal Transplantation

Study	No. of Patients	Mean Follow-up	Success Rate[a] (%)
Stollsteimer et al[16]	22	40 mo	57
Rath et al[17]	23	54 mo	Not provided
Ryu et al[18]	28	33 mo	Not provided
van Arkel and de Boer[19]	57	60 mo	Lat, 88; med, 66
Wirth et al[20]	23	14 yr	Not provided
Yoldas et al[21]	31	2.9 yr	68
Sekiya et al[22]	28	2.8 yr	86
Graf et al[23]	8	9.7 yr	13
Noyes et al[24]	38	40 mo	Not provided
Verdonk et al[25]	101	7.2 yr	Lat, 84; med, 72
Cole et al[26]	39	33.5 mo	Lat, 93; med, 68
Sekiya and Ellingson[27]	25	3.3 yr	80
Verdonk et al[28]	38	12.1 yr	84
Rue et al[29]	30	3.1 yr	76
Alentorn-Geli et al[30]	15	36 mo	85.7
Ha et al[31]	36	31.4 mo	78
LaPrade et al[32]	40	2.5 yr	85
Vundelinckx et al[33]	34	8 yr, 9 mo	97
Ha et al[34]	22	24.9 mo	91
Zhang et al[35]	18	24.9 mo	67

Lat = lateral, med = medial

[a] Success was defined as either good or excellent results based on the specific knee rating scale used or was defined by the individual study authors to include such parameters as a reduction in pain, increased knee function, and patient satisfaction.

graft does not necessarily correlate with its biomechanical function.

Complications have been noted following transplantation; graft tears are the most common (8.2%).[5] Infection rates appear to be similar to those following routine knee arthroscopy (ie, <1%). When infection has occurred, it is difficult to determine whether it was because of a contaminated graft or from the surgical procedure.

Several drawbacks and risks to transplantation exist. General matters of concern include the fact that there are a limited number of available grafts in tissue banks and that the grafts are relatively expensive. Anatomic risks relate to the accuracy of implantation, the reapproximation of the native meniscal horn insertion, the unknown effect of different graft-preservation and -fixation techniques on clinical outcome, and the neurovascular risks associated with an inside-out meniscal repair. As with the transplantation of any human tissue, there is also the risk of infectious disease transmission; bacterial infection is the most likely (0.5%).[5] To date, no instance of HIV infection following meniscal transplantation has been reported. The possibility nevertheless exists; the reported risk of HIV following the transplantation of musculoskeletal tissue has been estimated at approximately 1 in 1.6 million.[38] There is also the potential for an immune response resulting from class I and II histocompatibility antigens following transplantation. Rodeo et al[39] found B lymphocyte and cytotoxic T cells in 9 of 12 deep-frozen grafts. In their series, the clinical outcome was not related to this immune response, although the histologic scores were better in patients without this response.

Despite the limitations, meniscal grafts appear to decrease tibiofemoral pain, with subjective improvement in symptoms noted in approximately 70% of patients.[17,19,24,25,28] Similarly, there seems to be an increase in activity level over the short term. These grafts may provide some chondroprotective effects and improve joint stability over the short term. However, most grafts demonstrate some degree of shrinkage on MRI as well as partial or complete extrusion, variable degrees of signal changes, and tears. As a result, most transplants will likely fail over the long term. Nevertheless, this procedure can be effective in terms of improving symptoms and function before the patient becomes an appropriate candidate for arthroplasty.

Meniscal Replacement

Alternative options for meniscal replacement are being developed. Although none of the technologies listed below is currently approved by the Food and Drug Administration (FDA) for clinical use in the United States, orthopaedic surgeons should be aware of options that may become available.

Collagen Meniscal Implant

The collagen meniscal implant (CMI) is a bioresorbable collagen matrix designed to serve as a template for ingrowth of new meniscal tissue (Figure 2). The CMI requires a meniscal rim and intact anterior and posterior meniscal horns for attachment.[40,41]

Following numerous in vitro and in vivo analyses, the CMI underwent phase I[42] and phase II[40] feasibility studies. Medium-term follow-up of the phase II cohort demonstrated good clinical outcomes, with an average defect fill of 69% on second-look arthroscopy at a minimum of 5 years postimplantation.[41] Rodkey et al[43] reported the medium-term results of a prospective, randomized trial that compared the CMI with partial meniscectomy. This study involved 311 patients with either a symptomatic medial meniscal tear (acute group) or previous partial medial meniscectomy (chronic group). No differences were seen in the acute arm of the study, which compared these treatment approaches in patients with no previous surgery on the meniscus. In the chronic group, which involved patients who had a history of at least one previous partial meniscectomy, those who received the CMI had a greater recovery of activity and fewer reoperations.

Two recent studies have reported long-term (>10 years) results using the CMI. A series of 25 patients with a minimum 10-year follow-up reported sustained pain relief and functional improvement with very little joint space narrowing and a failure rate of 8%.[44] A comparative long-term study with a minimum 10-year follow-up reported improved pain, activity level, and radiologic outcomes in patients treated with the CMI compared with patients treated with partial meniscectomy alone.[45] This study was limited by selection bias, however, because the patients chose which surgery would be performed. Furthermore, it is difficult to interpret the radiologic outcome because joint space width was reported at the final evaluation, not the change in joint space over the course of the study period. Nevertheless, a growing body of evidence indicates that the CMI can at least be tolerated over the medium and long term and may provide some chondroprotection following a partial meniscectomy with intact meniscal roots. The CMI does not currently have FDA approval for use in the United States.

Figure 2

Photograph of a collagen meniscal implant. (Courtesy of William G. Rodkey, DVM, Vail, CO.)

Hydrogels

Hydrogels are biocompatible, biphasic materials with load rate–dependent mechanical properties; they have been proposed as a possible solution to meniscal replacement. Two small-animal models have demonstrated that hydrogel menisci could be durable.[46,47] However, in a large-animal model, hydrogel menisci demonstrated increased cartilage degeneration by 4 months compared with controls; the hydrogel menisci also developed radial splits in the posterior one third within 1 year of implantation.[48] Although hydrogels with improved material properties and surface characteristics may eventually prove to be useful, there are no clinical studies to date of hydrogels used for meniscal replacement.

Polymer Scaffold

A novel synthetic, biodegradable, acellular scaffold composed of aliphatic polyurethane (Actifit; Orteq Bioengineering, London, UK) has recently become available in Europe as an alternative option for partial meniscal replacement (Figure 3). Consisting of polycaprolactone and urethane segments, the scaffold degrades slowly over 5 years, starting with hydrolysis of the ester bonds in the polycaprolactone segments.[49] The more stable urethane segments may be phagocytized over time by macrophages or giant cells; alternatively, they may integrate into the surrounding tissue.[50,51] The scaffold has been shown to improve contact area and pressure in a sheep cadaver model.[52] A preclinical canine study found tissue ingrowth onto the scaffold and integration with the surrounding capsule by 6 months.[53] A recent case series reported tissue ingrowth within 3 months and viable fibrochondroblast-like cells after 12 months in human medial and lateral meniscal defects.[54] Two-year results in a case series of 52 patients (34 medial meniscus, 18 lateral meniscus) demonstrated clinically and statistically significant improvements from baseline in all clinical outcomes, including IKDC score, Knee injury and Osteoarthritis Outcome Score, and Lysholm score.[55] More than 90% of patients demonstrated stable or improved International Cartilage Repair Society articular cartilage scores on MRI at 24 months compared with baseline. Actifit does not cur-

Figure 3

Photograph of the Actifit implant. (Courtesy of Orteq Bioengineering, London, UK.)

rently have FDA approval for use in the United States.

Stem Cells

Interest has been growing in the use of stem cells in orthopaedic surgery. Several recent reports have been published of experimental models using mesenchymal stem cells to replace meniscal tissue.[56-60] These typically involve a stem cell–seeded scaffold modulated to generate meniscus-like tissue. Studies have demonstrated regeneration of the meniscus using a seeded scaffold in rat,[58] rabbit,[61,62] and pig models.[57] The latter study demonstrated a substantial improvement in meniscal healing compared with that in controls, which essentially exhibited no healing. However, the mechanical properties of the repair tissue were inferior to those of the intact meniscus. Stem cell–based implants are still in the investigative stage but may become available for preclinical studies in the near future. Human trials likely are a distant prospect.

Summary

The meniscus plays an important role in protecting the health of the knee joint. Once the meniscus has been torn and is removed from the joint, options are limited to replace this tissue. Meniscal allograft transplantation is a viable option showing increasing evidence of clinical utility, although the high cost, limited availability, and risk of disease transmission from allografts may preclude their widespread use. Options such as the CMI or Actifit scaffold are under investigation as potential partial meniscal replacements. In the future, stem cells may provide an alternative, potentially autogenous, source of meniscal tissue to regenerate the resected segment. Even with these advances, however, surgeons should continue to attempt meniscal repair whenever feasible and resect as little meniscal tissue as possible in tears that are deemed irreparable.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 4 and 43 are level I studies. Reference 45 is a level II study. Reference 37 is a level III study. References 3, 16-26, 28-36, 40-42, 44, 54, and 55 are level IV studies.

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