Meniscal Repair and Reconstruction

Gregg J. Jarit, M.D., and Joseph A. Bosco, III, M.D.

Abstract

Meniscus injuries are one of the most commonly encountered problems by orthopaedic surgeons today. Surgical techniques for the treatment of meniscal tears are evolving. While many tears can only be treated with partial meniscectomy, there are an increasing number of surgical techniques to repair or reconstruct the meniscus. Because of the large increases in contact pressures across the articular cartilage due to loss of meniscal tissue, there has been increased focus on preventing the development of degenerative joint disease from meniscal injuries requiring partial or subtotal meniscectomy. Some of these newer techniques include allografts, scaffolds, collagen implants, and repair enhancements. The common goal of these newer techniques is to preserve or restore as much normal, functioning meniscal tissue as possible. This review aims to review the various techniques and history of meniscus repair as well as examine of the newer techniques being introduced to reconstruct or replace the meniscus.

Meniscal surgery is among the most common orthopaedic procedures performed today. Emphasis has been placed recently on preservation of meniscal tissue in the knee due to the various functions of the menisci. These include load sharing, shock absorption, reduction of joint contact stresses, increase in joint congruity and contact area, articular cartilage nutrition, passive stabilization, and limitation of extreme flexion and extension. It has also been shown that removal of the lateral meniscus can result in a 235%-335% increase in contact forces on articular cartilage of the knee. This review will focus on the various surgical procedures designed to preserve the meniscus, including meniscal repair, allograft, and reconstruction.

Anatomy

The medial meniscus is shaped like a “C” and attached to the tibial plateau, primarily through the coronary ligament, which is firmly attached with the deep medial collateral ligament. The lateral meniscus is circular in shape and is attached to the capsule along its circumference, except at the popliteal hiatus. This attachment is less developed than the medial meniscus, making it more vulnerable to tearing in a traumatic event. Circumferential fibers of the meniscus resist hoop stresses, and radial fibers resist shear stresses. Within the lateral compartment, the lateral meniscus absorbs 70% of the load, while the medial meniscus absorbs 50% of force transmitted through the medial compartment. Blood is supplied to the peripheral 10%-25% of the menisci through the geniculates via the perimeniscal capillary plexus. The remainder of the meniscus is supplied by diffusion or mechanical pumping.

Diagnosis

The most frequent presentation of a meniscal tear is pain and mechanical symptoms, which include locking, catching, instability, and difficulty with deep knee bending. There is usually an inciting traumatic event in younger patients, but this is not always the case. Physical examination usually reveals joint line tenderness, which is a sensitive but nonspecific sign. Apley’s compression test and McMurray’s grind test are both specific but not sensitive. Magnetic resonance imaging (MRI) is the imaging modality of choice for the
Meniscal repair was first described, in 1883, by Thomas Annandale. In 1936, King reported that a meniscus in a canine model could heal with adequate blood supply. In the 1980s, by the all-inside repair described by Morgan in 1991. The outside-in, outside-in, all-inside, and repair enhancement (Table 1).

<table>
<thead>
<tr>
<th>Type of Repair</th>
<th>Indications</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Inside-Out</td>
<td>All tears except direct posterior</td>
<td>Highest mechanical strength</td>
<td>Incisions</td>
</tr>
<tr>
<td>Outside-In</td>
<td>Anterior horn (lateral meniscus)</td>
<td>Less risk of neurovascular injury</td>
<td>Arthroscopic injury</td>
</tr>
<tr>
<td>All-Inside</td>
<td>Body and posterior tears</td>
<td>No incisions</td>
<td>Increased cost</td>
</tr>
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</table>

- **Meniscal Repair**

Meniscal repair is commonly performed in conjunction with an anterior cruciate ligament (ACL) reconstruction. Patient age is a controversial topic, but it is generally accepted that younger patients are better candidates for meniscal repair. The types of repair include inside-out, outside-in, all-inside, and repair enhancement (Table 1).

### Inside-Out Repair

Inside-out repair with vertical mattress sutures is considered the “gold standard” of meniscal repair. This repair is performed arthroscopically with the use of cannulas to protect the articular cartilage. Nonabsorbable suture is used and long, flexible needles are utilized to pass the suture through the meniscus. The needle is passed through both portions of the tear, the joint capsule, and then the skin. There is a second needle attached to the other end of the suture, which is then passed in the same fashion to create a vertical or horizontal mattress configuration. A small incision is then made where the sutures have exited the capsule and skin. For medial meniscal repairs, the incision is best placed in a posterome-dial location behind the medial collateral ligament to avoid the saphenous nerve. It should be centered with two-thirds of the incision below the joint line. For lateral meniscal tears, the incision should be made behind the lateral collateral ligament, just anterior to the biceps femoris tendon at the joint line. Care must be taken to avoid the peroneal nerve, which runs posterior to the biceps tendon at this location. The knee should be flexed and retractors placed posteriorly to protect the nerve. Inside-out repair is indicated for all tears but is difficult for directly posterior tears, due to danger to the neurovascular structures posterior to the knee.

### Outside-In Repair

Outside-in repair is performed by introducing a needle from the skin, through the joint capsule, and through both fragments of meniscus. The suture is snared arthroscopically and arthroscopic knot tying is performed. The technique allows the use of smaller skin incisions. It is best used for anterior horn tears, especially of the lateral meniscus. In the past, large Mulberry knots were used with this technique; however, these knots were larger and not as strong as vertical mattress sutures, which are used today.

### All-Inside Repair

All-inside meniscal repair utilizes various devices, including arrows, tacks, staples, screws, and suture anchors. These devices are passed arthroscopically. The advantage of an all-inside repair include the lack of additional incisions, smaller neurovascular risk, more flexible fixation of fragments, and possibly decreased operative times. The disadvantages include increased cost, implant migration, foreign body reaction, inflammation, chondral injury, and implant failures. A learning curve with each of these techniques is associated with the use of these devices, and arthroscopic knot tying is sometimes required. These devices also have lower mechanical strength than the inside-out vertical mattress sutures.

Meniscal arrows were a popular type of all-inside implant. They came in variable sizes and were placed 3 to 4 mm apart through both meniscal fragments. They were able to hold unstable fragments in place to allow for healing. Initial results were promising, but more recent studies have shown
that these results deteriorate over time. Lee and Diduch reported a 90.6% success rate at 2.3 years, but this rate decreased to 71.4% at 6.6 years. A review of 14 studies by Lozano reported failure rates from 5%–43%. Gifstad and colleagues reported a 41% failure rate in 118 patients at 4.7 years.

The latest advance in the all-inside repair is the meniscal repair device with pre-loaded and pre-tied irreversible sliding knots. The sutures are self-adjusting and are delivered with a needle through a cannula after the repair site is abraded with a “backstop” or “top-hat.” These have become the most widely used all-inside devices; however, there are currently no level I studies of their results (Table 2). One level II study evaluated 20 repairs at 22 months and reported seven clinical failures (35%). Haas and coworkers recently reported 2 year results of the FasT-Fix (Smith and Nephew, Memphis, Tennessee) all-inside device in 42 patients. There was an 86% success rate (91% with concomitant ACL reconstruction and 80% with isolated repairs). Secondlook arthroscopy was performed in eight patients with no evidence of articular cartilage damage from the devices. Barber and associates evaluated the Rapidloc (Depuy Mitek, Raynham, Massachusetts) device in 32 patients at 31 months follow-up and reported an 87.5% success rate. On second-look arthroscopy, one patient had chondral grooving. Quinby and colleagues recently reported a 91% success rate in 54 patients with these devices. Overall, studies have shown failure rates from 0% to 45%, with better results seen with concomitant ACL reconstruction.

**Repair Enhancement**

Another technique to aid meniscal healing is promotion of healing with local delivery of growth factors. The first of these was repair enhancement through use of a fibrin clot. In 1988, Arnoczky and coworkers reported that fibrin clot can act as a chemotactic and mitogenic stimulus for reparative cells in the meniscus. It can also serve as a scaffold for connective tissue proliferation, which can subsequently be converted to fibrocartilaginous repair tissue. It was thought to be best suited for isolated meniscal repairs. In patients with concomitant ACL reconstruction, it is believed that the increased bleeding from the ligament repair may provide a similar stimulus for meniscal repair. Fibrin clot is made by utilizing 40 ml of venous blood. It is stirred with a glass rod until it adheres. Sutures are placed in the meniscal tear but left loose. The clot is applied to the tibial surface underneath the tear site. The sutures are then tightened to trap the clot. Henning and associates were the first to report fibrin clot results in 1990, and showed that the failure rate of repair decreased from 64% to 8% with use of a fibrin clot. Other techniques that potentially aid in healing that are utilized include trephination and rasping of the tear surface to cause bleeding.

**Meniscal Allograft**

When a patient has undergone prior extensive partial meniscectomy, meniscal allograft can be considered. These patients often had irreparable bucket-handle tears or a resected discoid lateral meniscus. In addition, patients undergoing revision ACL reconstruction have often had multiple traumatic events to their knee, resulting in a lack of meniscal tissue. Meniscal allograft was first performed, in 1984, by Milachowski, and first reported in the United States by Garrett and Steensen, in 1991. In 2002, 4000 allografts had been performed, with over 800 cases done annually. In 2000, Alhalki and colleagues published data demonstrating that meniscal allografts reduce the mean contact pressures on the articular cartilage by 75%. An animal study, in 2000, compared articular cartilage from knees with a meniscal allograft with knees after a total meniscectomy. The allograft group had a 40% reduction in macroscopic damage and a 50% reduction in area of damage. The investigators noted that the implant must be appropriately sized and positioned to achieve these results.

Patient selection is the key to success with this procedure. All relevant information should be collected, including operative reports and arthroscopic photographs. Physical examination should include evaluation of gait, lower extremity alignment, and ligament status. The presence of joint line tenderness, positive McMurray’s sign, and effusion should also be determined. Other possible sources of pain, including lower back, hip, and vascular causes, should also be excluded. Plain radiographs should include weightbearing anteroposterior (AP) views at 0° and 45° of flexion, a

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**Table 2 Meniscal Repair Devices**

<table>
<thead>
<tr>
<th>Implant</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Authors</th>
<th>Success Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrow</td>
<td>Conmed</td>
<td>Tack device</td>
<td>Lee and Diduch</td>
<td>90.6% @ 2 yrs, 71.4% @ 6 yrs</td>
</tr>
<tr>
<td>Biostinger</td>
<td>Conmed</td>
<td>Cannulated tack device</td>
<td>Barber, et al.</td>
<td>91%</td>
</tr>
<tr>
<td>FasT-Fix</td>
<td>Smith and Nephew</td>
<td>Two pre-loaded 5 mm suture anchors connected by #0 braided suture</td>
<td>Quinby, et al.</td>
<td>91% + ACL</td>
</tr>
<tr>
<td>Rapid LOC</td>
<td>Mitek</td>
<td>Backstop anchor connected to a top-hat by #2-0 preloaded suture</td>
<td>Barber, et al.</td>
<td>87.5%</td>
</tr>
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Different insertion techniques for meniscal allograft. One of the performed to reach the posterior horn. There are many different aspects of the corresponding condyle must be to a bleeding rim. Often a notchplasty of the inferior and is not present. The remaining meniscal tissue is debrided articular cartilage is evaluated to ensure too much damage significantly stronger than with sutures alone. On the medial, a bone block or bone plugs can be used. On the lateral, usually, a block is used because of the proximity of the knee is unstable, a ligament reconstruction can be performed concomitantly. There should be no more than mild degenerative changes on radiographs. Relative contraindications include obesity, skeletal immaturity, inflammatory arthritis, previous septic arthritis, or synovial disease (Table 3). The goals of surgery are pain-free activity and the possible delay or prevention of the progression of osteoarthritis. It may also increase the success of concomitant ACL reconstruction. Evidence for return to athletics is unclear at this time.

A successful meniscal allograft transplantation procedure starts with appropriate size matching. Dienst and coworkers showed that an oversized graft increased the forces across the articular cartilage; however, their results also demonstrated increased forces across the meniscal tissue if the graft was undersized. Sizing is performed with AP and lateral radiographs of the knee using a magnification marker. A length (AP diameter) adjustment of 80% is then performed for the medial compartment and 70% for the lateral compartment. No adjustment is required for the width of the graft. The implant should be fresh frozen or cryopreserved. This provides the least risk of biomechanical degradation and disease transmission.

While sutures and bony fixation can be used for the transplant, bony fixation is generally preferred. Alhalki and associates showed that fixation with bone blocks was significantly stronger than with sutures alone. On the medial side, a bone block or bone plugs can be used. On the lateral side, usually, a block is used because of the proximity of the horns. First, a diagnostic arthroscopy is performed, and the articular cartilage is evaluated to ensure too much damage is not present. The remaining meniscal tissue is debrided to a bleeding rim. Often a notchplasty of the inferior and posterior aspects of the corresponding condyle must be performed to reach the posterior horn. There are many different insertion techniques for meniscal allograft. One of the commonly used techniques is the bone bridge technique in which a medial or lateral parapatellar incision with mini-arthroscopy is performed, depending on the site of surgery.

The incision should be in line with the anterior and posterior horns. An 8 to 10 mm bone bridge is used and should be undersized by 1 mm. It is preloaded with two sutures through the block and two graft-passing sutures through the meniscal tissue. A line is drawn along the horn attachment sites and a 4 mm burr is used along that line. A depth gauge and insertion pin are placed under fluoroscopy. A 7 or 8 mm cannulated drill bit is used to open the tunnel for the bone block. The posterior cortex of the tibia is kept intact. A nitinol pin is passed through the capsule with a passing suture in its loop. The pin is pulled through and the allograft inserted through the arthrotomy. The bone bridge is reduced and can be fixed with interference screws at the bone interface and inside-out sutures for the meniscal tissue. An alternate fixation technique for the bone bridge is to place two trans-osseous bridge sutures. A 2-cm incision is made just medial to the tibial tuberosity and trans-osseous tunnels are drilled. The sutures are passed through these tunnels and tied over the anterior tibial cortex.

A different technique is used if bone plugs are being used for a medial meniscal repair. The plugs should be 6 mm, and sutures are passed through each bone plug. A posteromedial portal is often needed to visualize the posterior horn insertion site. The anterior site is anterior to the ACL footprint at the anterior margin of the tibial plateau. A spinal needle is passed through the posterior capsule. A polydioxanone sulfate (PDS) suture is passed into the joint through this needle, and a passing suture is placed through it. The posterior suture is pulled through to insert the graft via an expanded anteromedial portal. Similar transosseous tunnels are drilled to the proximal tibial cortex, as described above, and the sutures are passed through those tunnels. In this instance, the tunnels should start just lateral to the tibial tuberosity. After the 6-mm tunnels are drilled, the graft is seated as the knee is brought through several cycles and as tension is placed on those sutures. The sutures are tied over the tibial cortex, and the remainder of the meniscus is again repaired with inside-out vertical mattress sutures.

Complications of meniscal allograft include neurovascular injury, infection, immune response, retear, and iatrogenic damage to articular cartilage. Rehabilitation after surgery

### Table 3: Meniscal Allograft

<table>
<thead>
<tr>
<th>Indications</th>
<th>Contraindications</th>
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<tbody>
<tr>
<td>Prior extensive partial meniscectomy</td>
<td>Obesity</td>
</tr>
<tr>
<td>Prior total meniscectomy</td>
<td>Skeletal immaturity</td>
</tr>
<tr>
<td>None to mild Fairbanks changes on X-ray</td>
<td>Inflammatory arthritis</td>
</tr>
<tr>
<td>Less than 2 to 3 mm of joint space narrowing</td>
<td>Previous septic arthritis</td>
</tr>
<tr>
<td>Grade I/II wear on arthroscopy</td>
<td>Synovial disease</td>
</tr>
<tr>
<td>Age under 50 years</td>
<td>Malalignment</td>
</tr>
<tr>
<td></td>
<td>Grade III/IV wear on arthroscopy</td>
</tr>
<tr>
<td></td>
<td>Instability</td>
</tr>
</tbody>
</table>

lateral view, and a sunrise view. Bilateral lower extremity alignment films should be obtained, as well as an MRI to assess remaining meniscus, hyaline cartilage, and subchondral bone.

Suitable candidates for a meniscal allograft are under 50 years of age and with prior total or near total meniscectomy, pain in the involved compartment, less than 2 to 3 mm of joint space narrowing, only grade I/II wear on arthroscopy, a stable knee, and without malalignment. If the knee is unstable, a ligament reconstruction can be performed concomitantly. There should be no more than mild degenerative changes on radiographs. Relative contraindications include obesity, skeletal immaturity, inflammatory arthritis, previous septic arthritis, or synovial disease (Table 3). The goals of surgery are pain-free activity and the possible delay or prevention of the progression of osteoarthritis. It may also increase the success of concomitant ACL reconstruction. Evidence for return to athletics is unclear at this time.

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Complications of meniscal allograft include neurovascular injury, infection, immune response, retear, and iatrogenic damage to articular cartilage. Rehabilitation after surgery
includes a progressive strengthening program. Patients can expect to be able to do light running by 3 to 4 months and light recreational activities by 5 to 6 months. Squatting and hyperflexion are discouraged for at least 6 months. High load, repetitive impact activities are discouraged.

While there are several case series evaluating the results of allografts, there have been no level I or II studies. Verdonk and colleagues reported 28% failure of medial meniscal allografts and 16% failure of lateral allografts at an average of 7.2 years. The 10-year survival rate was 74.2% for medial and 69.8% for lateral allografts. The same group then evaluated clinical, radiologic, and MRI outcomes of 42 patients at 10 years and reported significant improvement in pain and function. The Fairbanks changes remained stable in 28% of patients, there was no further joint space narrowing in 41%, and on MRI, 35% had no progression of cartilage degeneration. The majority of patients had partial graft excursion. The overall failure rate was 18%, and those patients subsequently underwent total knee arthroplasty. Hommen and coworkers evaluated 14 medial and 8 lateral meniscal allografts at over 10 years follow-up and documented 25% medial and 50% lateral failure rate; 85% of patients underwent subsequent surgery. Cole and associates clinically evaluated 40 patients at 2 years and found that 77.5% were completely or mostly satisfied. There were seven failures (18%). Sekiya and colleagues evaluated 25 patients at 3.3 years with isolated lateral meniscal allograft and found that 96% of patients “believed function and activity level improved.” Patients who received bone blocks had better results than those with only meniscal allograft tissue. Joint space narrowing was a significant factor in poor outcomes. One level III study was performed evaluating patients who underwent ACL reconstruction with either meniscectomy/repair or allograft. The outcomes were similar overall, with the transplant group experiencing more swelling but greater amount of pain reduction. A comprehensive review by Matava showed the variety of results obtained with this procedure. Successful outcome percentages ranged from 12.5% to 100%. The more recent studies had 85% favorable outcomes. Favorable outcomes were more likely in the young or middle-aged patient with joint line pain and limited degenerative joint disease.

**Meniscal Augmentation Techniques**

There are several new approaches being developed to aid in the reconstruction of the damaged or removed meniscus. A polyvinyl alcohol gel (PVA-H) was developed by Kobayashi and coworkers. They reported on the implantation of 14 rabbits with PVA-H on one side and lateral meniscectomy on the other. There were early degenerative changes seen in the PVA-H group but these stabilized by 1 year, whereas the meniscectomy cohort had continued degeneration. In 2005, they reported their 2-year follow-up results. All implants were firmly attached, with no breakage. There were significantly more degenerative changes in the control group, and the PVA-H group had specimens with normal cartilage or only slight erosion. Kelly and associates studied a hydrogel implant in 14 sheep and compared it to sham, lateral meniscectomy, and allograft. Cartilage degeneration was seen by 4 months in the hydrogel group. At 2 months, there was no difference between groups, but at 4 months the hydrogel group had significantly more articular cartilage damage on the tibial plateau. At 1 year all hydrogel specimens had full-thickness cracks and significant osteoarthritis. To date, there have been no human studies with hydrogel.

Cook and Fox studied a bioabsorbable conduit made of poly-L lactide acid (PLLA). They compared the conduit to trephination and repair in 50 dogs. At 1 to 2 years, there was complete or partial healing in all conduits, whereas there was no healing in the control group. Most implants were retained. No articular cartilage damage was noted. Another alternative product consists of a bacterial cellulose gel, the use of which was reported in Sweden in 2007. It can be shaped into a meniscus, promotes cell migration, and is inexpensive. It was shown to be stronger than the collagen meniscal implants, but not as strong as meniscal tissue.

Cell-based implants have also been developed and tested in animal models. Weinend and colleagues studied a viral mesh impregnated with allogenic or autologous chondrocytes implanted into 17 swine. These were avascular lesions and were evaluated at 12 weeks. All samples had new scar-like tissue. Two of nine lesions with autologous chondrocytes had healed, and one of nine with allogenic chondrocytes also healed. The remaining samples had partial healing.

A more extensively studied implant is the collagen meniscal implant (CMI). In 1997, Stone and coworkers published results on a collagen scaffold with bovine type I collagen, hyaluronic acid, and chondroitin sulfate. All nine patients reported pain relief. There was one re-tear at 19 months and one reoperation for an irregular area of articular cartilage. There was a progressive increase in return to activities over the 3 years following the index surgery. Follow-up MRI revealed maturation of the implant over time and no evidence of an immune response. At second-look arthroscopy of four patients, there was a progressive invasion of collagen and meniscal fibrochondrocytes. Another study of eight patients with a 6 to 8 year follow-up reported half of patients with no pain and the other half with only mild pain. On second-look arthroscopy in three patients, two still had the implant in a reduced position. MRI revealed six patients with myxoid degeneration, two with normal signal but the implant was reduced in size, and one with no implant present.

A radiological study of collagen meniscal implants from 2007 evaluated 40 patients at up to 2 years postoperatively with MRI. At 6 months the CMI size and shape were normal in 35/40 patients and mildly abnormal in the
remaining five patients. At 12 months, the shape and size were normal in 33/40. There were new chondral lesions in 3/40 and marrow edema in 3/40.50

Future Directions
Enhancement of scaffold healing with cells, growth factors, or both, have also been studied for meniscal healing. Recent investigations have targeted biologic enhancement of meniscal healing. In one study, several growth factors have been applied to meniscal fibrochondrocytes, and extracellular matrix production was quantified. It was found that transforming growth factor-beta up-regulated both collagen and glycosaminoglycan production.51 The first report of stem cells used for meniscal repair was published recently. A hyaluronan-gelatin composite scaffold was placed into two groups of rabbits. The study group scaffolds were impregnated with autologous marrow-derived mesenchymal stem cells precultured for 14 days. In that group, 8/11 samples had meniscus-like fibrocartilage in the repair with integration of the scaffold into the native meniscus.

Summary
In summary, repair and reconstruction techniques for the meniscus are still evolving. Suture repair of appropriate meniscal tear patterns has been shown to have a good track record. For meniscal repair, inside-out vertical mattress sutures are the “gold standard” for repair, despite the increasing popularity of all-inside meniscal repair devices. There are few prospective, randomized studies of many of the newer implants that are currently being used. As the number of meniscal allografts performed increase, there will be more clinical data available to evaluate the techniques which are likely to provide the best results. In addition, procedures with gels, scaffolds, collagen and cell-based implants, growth factors, and stem cells may be developed to augment the reconstructive options.

Disclosure Statement
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

References