SPECIAL FOCUS SECTION

Meniscus Repair and Transplantation Techniques

MAJ Travis C. Burns, M.D.,[1] MAJ Jeffrey R. Giuliani, M.D.,[1] LTC Steven J. Svoboda, M.D.,[1] and LTC Brett D. Owens, M.D.[1]

ABSTRACT

Modern meniscal repair incorporates multiple techniques and adjunctive measures. The classic inside-out repair remains the gold standard and is most appropriate for a bucket-handle type tear of the medial or lateral meniscus. The all-inside technique has gained in popularity recently and has outcomes that approach those of the inside-out repair with decreased morbidity but increased cost. The choice of this technique is most appropriate for small tears requiring few sutures to repair. Outside-in repair can also be employed and is preferred for anterior horn tears. Surgeons may use a hybrid technique that incorporates all techniques in some challenging cases. Meniscal debridement is used for degenerative tears that are not amenable to repair. Meniscal transplantation is an option for symptomatic meniscal deficiency in young, active patients. This article discusses the technical considerations for meniscal debridement, repair, and transplantation.

KEYWORDS: Meniscus, repair

Menisci are vital to knee function for load transmission, joint congruency, reducing contact stresses, shock absorption, and as a secondary source of stability. While forces across the knee range from 2 to 5 times body weight during ambulation, the menisci protect the articular cartilage by load sharing, increasing contact area, and reducing peak contact stresses.[1] With the knee in full extension and weight-bearing, the menisci transmit approximately 50 to 70% of the load, which increases to 85% in 90 degrees of flexion. The tibial plateau does not match the radii of curvature of the femoral condyles, and the menisci improve joint congruity by accommodating for the difference.

The vascular supply to the meniscus dictates the tear locations amenable to repair. The menisci receive blood supply from the superior and inferior geniculate arteries with a contribution from the middle geniculate to the anterior and posterior horns. On average, the peripheral 10 to 30% of the medial meniscus and 10 to 25% of the lateral meniscus is vascularized in the adult meniscus.[2] While the entire meniscus is vascular at birth, by 9 months of age the central one-third is avascular.[3] The blood supply to the meniscus gradually diminishes during childhood, and by 10 years of age the vascular supply is similar to that of an adult.[1]

Stable, peripheral tears of the meniscus may heal with conservative treatment.[4] Although patients may experience symptomatic relief with conservative measures, unstable, symptomatic tears of the meniscus are unlikely to heal without treatment. There is also a potential for a tear to propagate from a reparable pattern to one not amenable to repair and successful healing.[1,5–7] This is particularly important in young patients with loss of motion secondary to a displaced meniscal tear.

[1]John A. Feagin, Jr., Sports Medicine Fellowship, Keller Army Hospital, U.S. Military Academy, West Point, New York.

Address for correspondence and reprint requests: LTC Brett D. Owens, M.D., John A. Feagin, Jr., Sports Medicine Fellowship, Keller Army Hospital, U.S. Military Academy, West Point, NY 10996 (e-mail: b.owens@us.army.mil).

J Knee Surg 2011;24:167–174. Copyright © 2011 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1 (212) 584-4662.

Received: January 1, 2011. Accepted after revision: June 18, 2011. Published online: August 18, 2011.

DOI: http://dx.doi.org/10.1055/s-0031-1286051.

ISSN 1538-8506.

Furthermore, the literature supports improved results of meniscal repair when performed within 8 weeks of injury.

Open meniscal repair was seen to have good results with the first series from DeHaven in the 1980s.[8,9] Arthroscopic repair has replaced open meniscal repair as instruments and techniques have improved over the past three decades. The most commonly used techniques will be described.

ARTHROSCOPY SET-UP

Arthroscopic meniscal repair is performed with a similar set-up to diagnostic knee arthroscopy. The authors prefer set-up that involves placing the patient in the supine position with the foot of the bed lowered, the contralateral extremity abducted in a well-leg holder, and the operative leg draped free over a lateral post or circumferential leg holder (Fig. 1). The authors prefer to set-up all knee arthroscopy cases in this manner, as to always have complete circumferential access to the knee if a repair is necessary. A tourniquet is placed on the upper thigh, although not commonly inflated, and fluid inflow is pump-modulated.

Diagnostic arthroscopy is performed through standard anteromedial and anterolateral portals. The posterior horns of the medial and lateral meniscus can be visualized by placing the arthroscope between the posterior cruciate ligament (PCL) and the medial femoral condyle or between the anterior cruciate ligament (ACL) and the lateral femoral condyle. A 70-degree arthroscope is valuable in this position to view the posterior horns. Posteromedial or posterolateral portals may also be placed but are rarely necessary.

Table 1 Indications for Meniscal Repair

Indications
Tear size larger than 1 cm
Active patient
Meniscal tissue amenable to repair
Most favorable conditions
Young patient
Location in the peripheral third (red-red zone: within 3–4 mm of capsule)
Vertical tear pattern
In conjunction with ACL reconstruction
Less favorable conditions (consider adjuncts)
Radial and flap tears
Location in the middle and central thirds of meniscus (red-white zone: within 3–6 mm of capsule) (white-white zone: central 3–4 mm of meniscus)

After a meniscal tear has been deemed appropriate for surgical repair (Table 1), unstable radial or flap tears are saucerized or excised. The meniscal bed is prepared with a 3.5-mm shaver or meniscal rasp to remove frayed edges and abrade each side of the repair to stimulate a bleeding response. Bucket-handle tears can be prepared while the meniscal tissue is displaced for better visualization and instrument access. After

Figure 1 Patient set-up for knee arthroscopy with operative leg draped free and the foot of the table dropped. The knee has circumferential access if needed for a meniscus repair.

completion of bed preparation, displaced meniscal tissue is reduced with a probe and valgus or varus stress.

INSIDE-OUT REPAIR

The inside-out technique was an improvement to traditional open repairs as arthroscopic visualization improved tear recognition and suture placement. Double-limbed flexible needles with nonabsorbable suture are placed through aiming cannulas placed through the anteromedial and anterolateral portals. A medial or lateral incision is made to retrieve the sutures and tie over the joint capsule. The technique is most amenable to meniscal tears involving the body or posterior horns of the medial or lateral menisci. Tears involving the anterior horn are difficult to access with this technique due to the angle of insertion from the anterior portals.

After completion of the arthroscopic preparation, the surgical approach for needle retrieval and suture tying is made. For medial meniscal repairs, a sterile marking pen is used to draw a 4-cm line just posterior to the medial collateral ligament (MCL) or in-line with the posteromedial aspect of the diaphyseal portion of the tibia. The incision is made from 1 cm above to 3 cm below the joint line. Scissors dissection is carried through the superficial soft tissue to the pes anserine fascia with care to avoid injury to the saphenous nerve. The fascia is incised in-line with the skin incision to expose the deep MCL, capsule, and posterior oblique ligament. The pes anserine fascia with the gracilis and semitendinosus are retracted posteriorly. The medial gastrocnemius is then elevated with blunt dissection off the posterior capsule. The joint line can be palpated along the posterior capsule and a pediatric speculum, Henning retractor, or sterile spoon is placed to retract the gastrocnemius and protect the posterior neurovascular structures.

The posterolateral surgical approach is performed through a similar length incision placed just posterior to the lateral collateral ligament. After incision through the skin, scissors dissection is carried down to the biceps femoris and iliotibial band. An incision in-line with the skin incision is made in the interval between the biceps femoris and iliotibial band. The biceps femoris is elevated posteriorly and the lateral gastrocnemius is identified. Blunt dissection is used to elevate the lateral gastrocnemius from the posterior capsule. A pediatric speculum, Henning retractor, or sterile spoon is used to retract the lateral gastrocnemius and protect the neurovascular structures.

After the counter incision is made, the arthroscope is placed in the ipsilateral anterior portal as the side of the tear, so the opposite portal can be used for improved instrumentation angle. Placing sutures through the portals on the opposite side minimizes risk to the posterior neurovascular bundle. Zone-specific cannulas with varying angles of curvature are available for needle and suture passage (ConMed Linvatec, Largo, FL). In addition, multiple instrument sets are available that may facilitate suture passage; such as, double-barrel cannulas and triggered devices that incrementally advance the needle (SharpShooter, ConMed Linvatec, Largo, FL). However, the authors prefer the use of simple single-barrel cannulas with needles advanced by hand to allow for safe and reliable suture placement.

While the knee is placed under varus or valgus stress, the surgeon directs the appropriately angled cannula while a seated assistant holds the retractor and retrieves the passed needles. For medial meniscal repairs in patients with minimal opening under valgus stress, an 18-gauge needle can be used to trephinate the superficial MCL to allow for more separation of the medial compartment and improved access to the posterior meniscal body and horn. The tear pattern and meniscal reduction is analyzed with a probe or cannula tip to determine where initial suture placement will properly reduce the meniscal tear. Advancement of the needle 2 to 3 mm out of the cannula can allow for the needle to facilitate proper meniscal reduction prior to full advancement through the capsule. The authors prefer placing vertical mattress sutures (Fig. 2) alternating on the superior and inferior aspect of the meniscus when possible and horizontal mattress sutures when vertical mattresses are not possible. The zone-specific cannulas are used to place sutures in the anterior horn, mid-body, and posterior horn of either meniscus. Double-loaded straight flexible needles are used to place 2–0 nonabsorbable sutures. The needles are advanced in 5 mm increments with a needle driver and should not be advanced beyond 10 mm if the assistant holding the speculum cannot identify the needle. Sutures placed in the posterior horn are particularly difficult to ensure appropriate visualization and safe retrieval. The curve of the cannula should be used to direct the needle away from the neurovascular structures. Suture tails are tied sequentially from posterior to anterior with the knee in

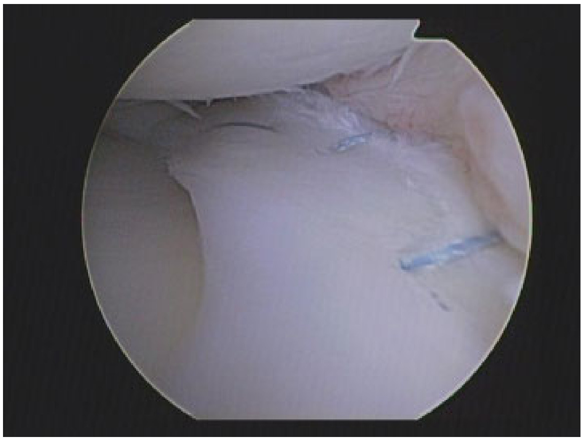


Figure 2 Arthroscopic photograph depicting the vertical mattress suture pattern used in an inside-out repair.

slight flexion. Care should be taken to ensure sutures are tied deep to the iliotibial band and over capsular tissue.

The inside-out repair is still considered the gold standard technique. The authors prefer this technique for all bucket-handle tears or large peripheral tears. This technique is also used for meniscal transplantation.

OUTSIDE-IN REPAIR

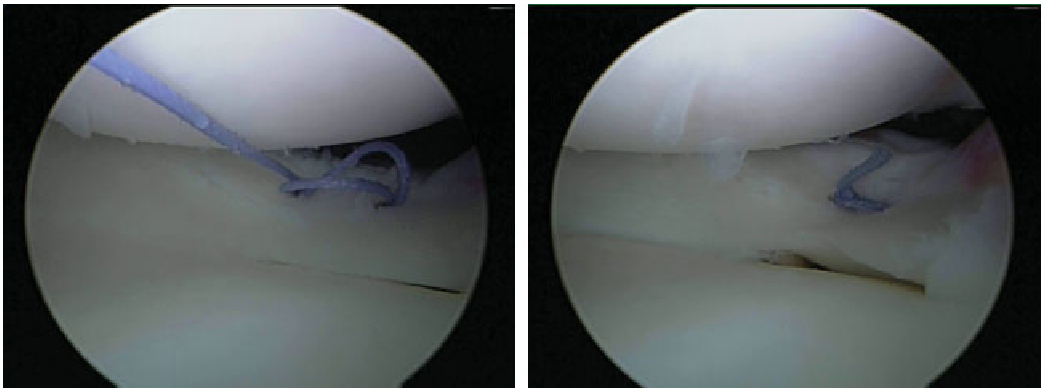
The outside-in meniscal repair technique involves passage of suture from outside the knee and retrieving it through an anterior working portal. The technique is most commonly used for anterior horn tears of the medial or lateral meniscus. The technique can be performed after a capsular approach has been performed or can be done percutaneously. In the percutaneous technique, an 18-gauge spinal needle is passed through the skin and through the meniscal tear. A 0 polydioxanone suture (PDS) is placed through the needle and retrieved out of the working anterior portal. A mulberry knot is tied and drawn back into the joint to reduce the meniscal tear. A second suture is placed in similar fashion. A small percutaneous incision is made over these sutures down to the capsule where they are tied together. Alternatively, this technique can be performed with a cannulated hook device used to retrieve the first PDS suture to eliminate a suture knot on the meniscal surface. A small percutaneous incision is made and used to retrieve both sutures to tie over the capsule. The outside-in technique can replace the single 4-cm incision for inside-out repairs with multiple smaller incisions. Due to concerns for neurovascular injury this technique is not commonly used for tears of the posterior body or horns. The authors prefer this technique for anterior body or anterior horn tears.

ALL-INSIDE REPAIR

All-inside meniscal repair has evolved significantly over the past two decades as surgeons and manufacturers have devised new systems to improve fixation strength, ease of use, and minimize complications. Early reports described fixation failure, adverse reactions to the materials, and chondral injury secondary to lose implants.[10–12] The first generation of devices consisted of arrows, darts, and screws. A single device placed across the meniscal tear through a specific cannula. These devices had low pullout strengths, poor ability to tension the repair site, and the potential to cause chondral damage from loose implants. Newer devices (i.e., Meniscal Cinch, Arthrex, Naples, FL; Fast-Fix, Smith & Nephew Endoscopy, Andover, MA) have a suture connecting two deployable buttresses and can be tensioned after placement (Fig. 3A, B). These devices theoretically tolerate higher loads to failure, only have suture material in the joint reducing the risk of chondral damage, and can be tensioned to reduce a gap in the tear site. Each manufacturer employs a specific instrument set and insertion handle to position, deploy, and tension the device. In general, the devices are applied from the contralateral anterior portal and allow horizontal and vertical mattress suture configurations without the need for a second incision for needle retrieval. The near portal may be necessary to apply sutures in the posterior horn of the menisci. Device placement in the posterior horn of the menisci can be within millimeters of the popliteal artery and the depth limiting device should be used to minimize risk to neurovascular structures.[13] These implants are more expensive than for the other repair techniques, but save time in the operating room and reduce morbidity associated with an open approach. The pullout strengths for newer implants are comparable to conventional suture techniques, but the inside-out vertical mattress is still considered the gold standard for meniscal repair.[14–18] The authors prefer the all-inside technique for posterior horn tears or small tears requiring fewer than three sutures for repair.

ROOT AVULSION REPAIR

The anterior and posterior horns are anchored to the subchondral bone through insertional fibers, and the



A B

Figure 3 All-inside meniscus repair with placement of bioabsorbable anchors with pretied sliding knot (A) allowing tension to be placed across the repair site (B) without the knee for a counter incision.

anterior horns are attached via the intermeniscal ligament. The posterior horn of medial meniscus translates up to 5 mm with knee flexion to accommodate femoral rollback, while the posterior horn of the lateral meniscus translates up to 11 mm.[1]

The posterior horn is most commonly injured with concomitant ligamentous disruptions. Disruption of the horns of the menisci lead to loss of the meniscal hoop stress resistance, meniscal extrusion, and abnormal joint loading.[19] As the horns of the meniscus are avulsed from the subchondral bone, classic suture techniques to the capsule do not restore anatomical placement.

Root repair is performed initially with preparation of the subchondral attachment with a 3.5-mm shaver or curette to establish a healing surface. These sites can often be accessed through the intercondylar notch medial to the PCL or lateral to the ACL. Otherwise, a posteromedial or posterolateral portal can be made under needle localization. A small cannula is placed in the posterior portal and used for instrument access to the posterior horns. After site preparation, a suture shuttling device (Suture Lasso, Arthrex, Naples, FL) or antegrade suture passer (Scorpion Suture Passing Device, Arthrex, Naples, FL) is used to pass a horizontal mattress suture configuration into the posterior horn of the meniscus. A tibial aiming guide is used to drill a 2-mm tunnel from the medial tibial cortex to the horn insertion. A looped suture placed through the tunnel is retrieved out of an anterior portal and used to shuttle the meniscal horn suture. The sutures are then tied over a button on the tibial cortex. Alternatively, a suture anchor can be placed in the horn insertion through a posterior portal to obviate the need of a tibial tunnel. Avulsions of the posterior horn of the lateral meniscus are more frequently encountered during ACL reconstruction, and these can be repaired in similar fashion by passing the shuttled suture with the graft into the tibial tunnel. Anterior horn avulsions can be repaired with a similar shuttling technique and secured with a push-in anchor (PushLock, Arthrex, Naples, FL) into the anterior insertion site.

BIOLOGIC ADJUNCTS

Synovial abrasion, trephination, and fibrin clot application are the most commonly used biologic augmentation techniques. Synovial abrasion and trephination can be used without suture or implant fixation in small, less than 1 cm, stable tears. The techniques are most commonly indicated in hypovascular regions of the meniscus; red-white zone (between 3 and 5 mm from meniscocapsular junction), white-white zone in young active patients (between 6 and 9 mm from capsule), and radial or flap tears in young active patients.[1]

Synovial abrasion with a rasp (Fig. 4A) stimulates the formation of a vascular pannus that provides increased vascularity to the healing meniscus. Trephination theoretically promotes vascular access channels to form into the repair site from the more vascular peripheral tissue. Under arthroscopic visualization trephination is performed with an 18-gauge needle. Multiple small perforations are performed from outside-in or inside-out with care not to exacerbate the tear or to damage the articular surfaces. Another useful technique to encourage vascular infiltration is microfracture in the intercondylar notch (Fig. 4B, C)

Fibrin clot augmentation is proposed to apply chemotactic and mitogenic stimulus, as well as a scaffold for fibrocartilaginous reparative tissue formation. Multiple manufactures offer equipment sets to produce a stable fibrin clot from a sample of the patient's blood. Alternatively, a peripheral blood draw can be prepared in a sterile fashion with mechanical stimulation to result in platelet activation (Fig. 4D). The semisolid clot is placed into the repair site by direct injection or passage along a suture. If direct injection is used it can be facilitated by placement through a cannula. The clot is placed at the repair site after the sutures are placed, but prior to tensioning and tying over the capsule. Once placed by direct injection, the sutures can be tensioned to hold the clot while the cannula is removed. Alternatively, the fibrin clot can be placed in the repair site by passing a suture from inside-out, placing the clot on the suture, tying a knot behind the clot, and then drawn into the defect with tension on the suture. The mattress sutures can then be tied to stabilize the clot position and the suture can be withdrawn from the portal. The authors currently prefer the use of platelet-rich plasma when a clot is required to augment healing as the handling properties of this clot allow for easier passage into the repair site (Fig. 4E, F).

The authors do routinely perform some form of adjunctive therapy in all meniscal repairs. In patients not undergoing concomitant ACL reconstruction, notch microfracture and synovial rasping are performed. Also needle trephination is also routinely performed. Insertion of a fibrin clot or platelet-rich plasma clot is reserved for cases with complex tears in the white-white zone or in revision situations.

MENISCAL ALLOGRAFT TRANSPLANTATION

Meniscal allograft transplantation (MAT) is indicated in symptomatic patients, generally younger than 50 years of age, without significant arthritic changes. Successful meniscal transplantation necessitates appropriate mechanical alignment, ligamentous stability, and appropriate treatment of focal chondral injuries. For medial and lateral meniscus allografts, the authors prefer to use a bone plug technique, as described by DeBerardino.[20] The graft is prepared with 8 mm bone plugs for the anterior and posterior horns with passing sutures

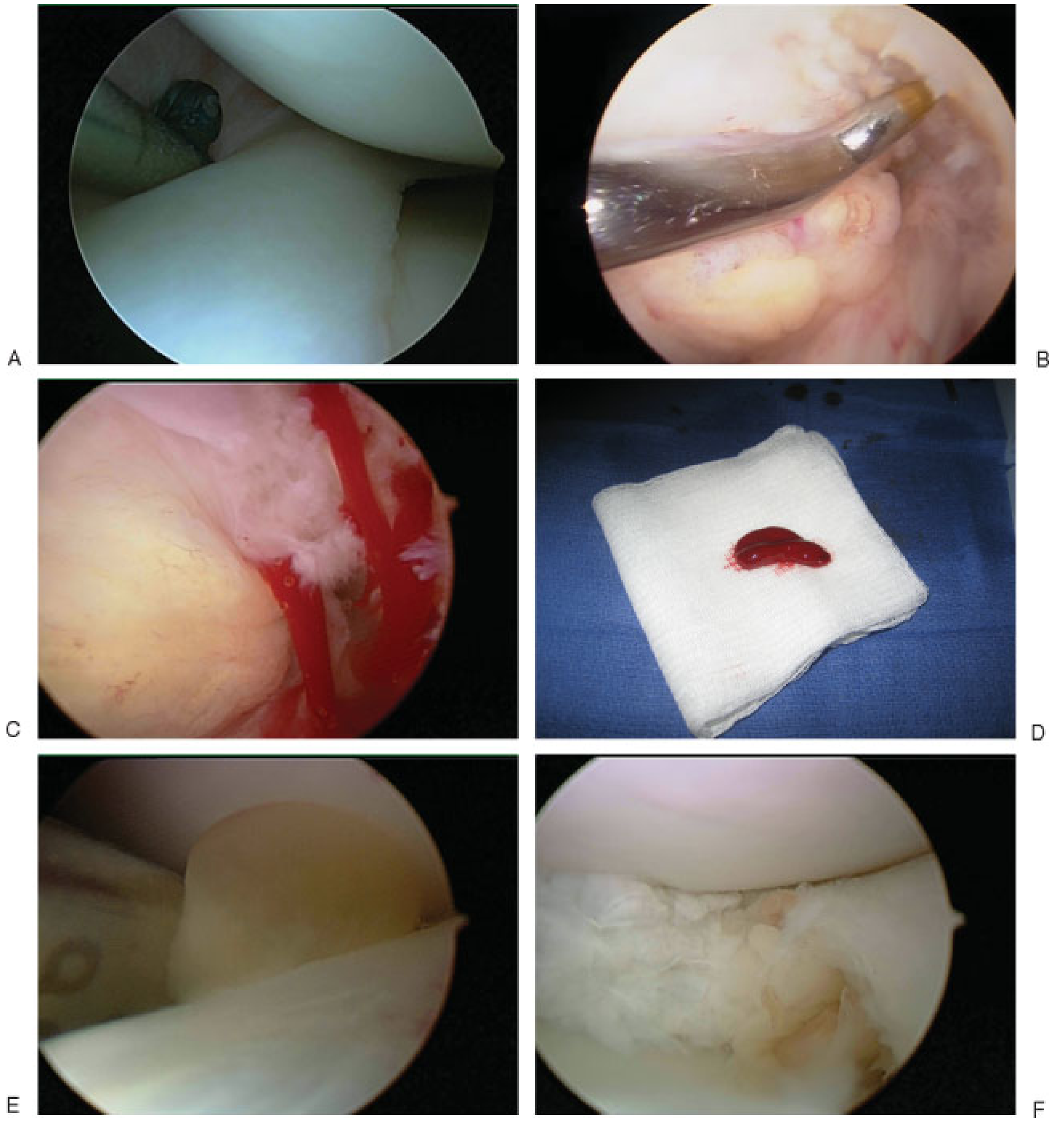
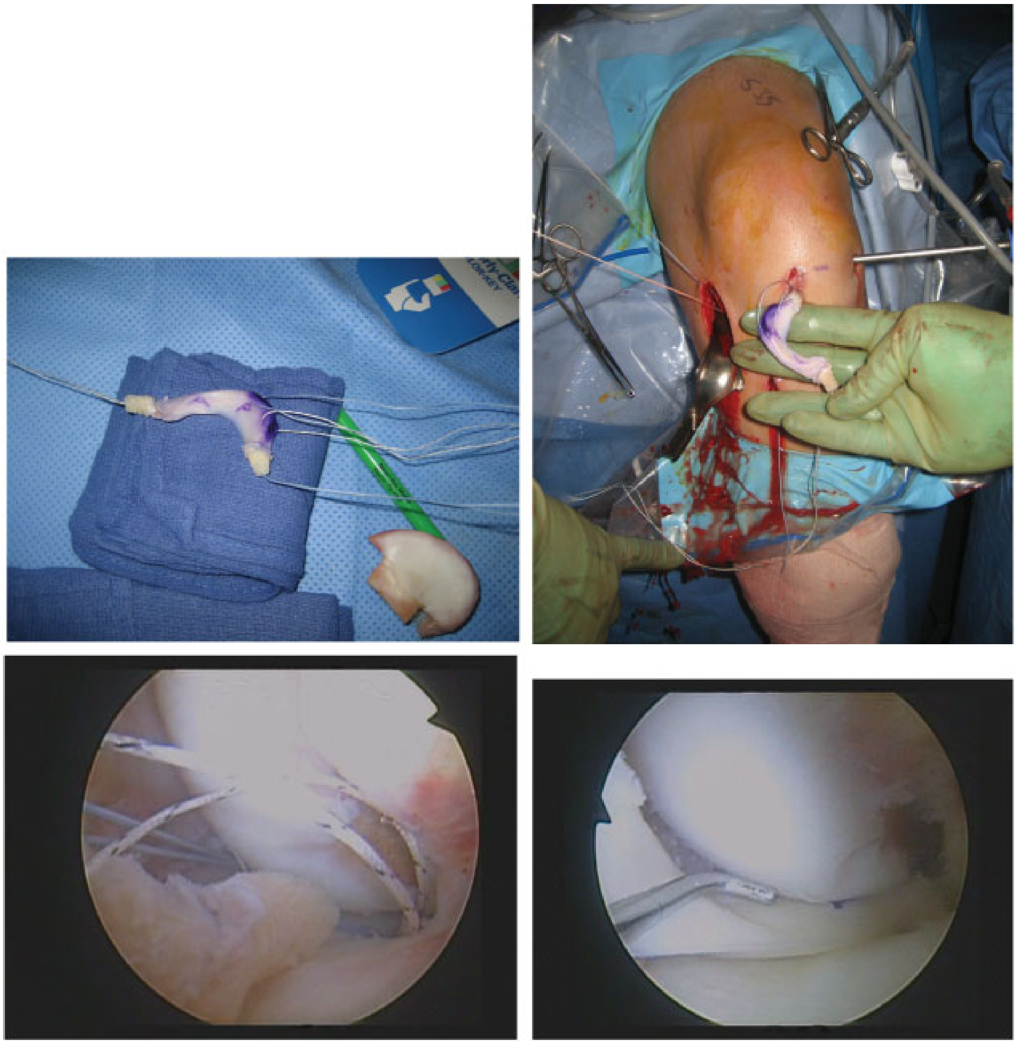


Figure 4 Adjunctive measures that can improve the healing of a meniscal repair include synovial rasping (A), microfracture in the intercondylar notch (B, C), fibrin clot insertion (D), or platelet-rich plasma insertion into repair site (E, F).

through the center of both bone plugs after grasping sutures are placed in the horn tissue (Fig. 5A). A tibial aiming device is used to make a 9-mm socket with a flip cutter or retrodrill at the site of the posterior root and a shuttling suture is passed. It is necessary to remove a portion of the medial or lateral tibial spines for graft placement, but care must be taken to not disrupt the articular surface of the femoral condyle or tibial plateau. Posterior horn sutures are shuttled through the tibia and two sutures through the posterior meniscal body are shuttled out of the posterior capsule prior to placement of the graft into the knee. The graft is inserted through an enlarged anteromedial or anterolateral portal (Fig. 5B) with tension on these three suture strands (Fig. 5C). Once the posterior root bone plug is pulled into its receptive socket and secured over a post or button, the knee is placed into varus (for lateral MAT) or valgus (for medial MAT) to facilitate meniscal horn reduction (Fig. 5D). The meniscal body repair is performed through an inside-out technique. The anterior horn is similarly tied over a button through a tibial tunnel or secured into a receptive tunnel with a friction-locking suture anchor device (PushLock, Arthrex, FL).

OUTCOMES

Outcome studies after total meniscectomy in young patients have revealed early development of osteoarthritis.[21,22] Partial meniscectomy in ligamentously stable knees have had better results with better than 80% good to excellent results after 15 years.[23] The patient age, activity level, alignment, concomitant chondral injury, location of the tear, and tear pattern are important variables that likely influence outcome after meniscectomy and repair. As increasing portions of the posterior horn of the medial meniscus is resected, there



A B C D

Figure 5 Medial meniscal allograft transplantation is performed arthroscopically using allograft prepared with bone plugs from hemiplateau (A), passed through an enlarged anteromedial portal (B). After the posterior bone plugged is passed (C) into its receptive socket, the meniscus is reduced under the condyle (D), the anterior bone plugged is secured in a similar fashion and an inside-out repair is performed.

is increasing amounts of stress across the tibiofemoral articulation. Furthermore, a full thickness disruption of the circumferential fibers, as seen with radial tears, is structurally similar to a total meniscectomy.[24] As the importance of the menisci were elucidated, efforts at surgical repair evolved.

Studies have shown a success rate of 75 to 92% with inside-out meniscal repair.[25,26] In a large series of inside-out repairs involving the avascular central portion of the meniscus, Rubman et al reported 80% of patients to be asymptomatic 3.5 years after surgery but follow-up arthroscopy revealed complete healing in only 25% and partial healing in 38%.[27] The significance of this discrepancy between healing rates and subjective outcomes is unknown. The clinical success of incompletely healed repaired menisci support attempted meniscal repair in young patients as the potentially long-term benefits and clinical success outweigh the cost of failure and need for revision surgery.

There have been no randomized prospective trials comparing inside-out meniscal repair technique to all-inside technique with the newest generation of surgical implants. Two prior studies comparing the two techniques with ACL reconstruction demonstrated no difference in outcomes.[28,29] Regarding suture configuration and currently available all-inside devices, multiple studies have revealed a difference in pullout strength. Meniscal repair with inside-out vertical mattress sutures is considered the gold standard repair and has been shown to provide the greatest strength of repair in biomechanical models.[30,31] On the other hand, the Fast-Fix has demonstrated comparable strength to vertical mattress sutures in other studies and superior strength to other all-inside devices.[14–17,32]

In physiologically young patients, we attempt repair when possible. Radial tears extending to the capsule, we repair with simple sutures and resect the unstable meniscal tissue in the avascular white-white zone. For tears in the avascular zone and not associated with ACL reconstruction, we favor augmentation with a fibrin clot to enhance healing potential.[33,34] Our surgical technique is largely dictated by tear size: for displaced, large tears we perform an inside-out technique and for stable tears less than 2 cm we perform an all-inside arthroscopic repair.

REFERENCES

1. Brockmeier SF, Rodeo SA. Meniscal Injuries. Vol II. 3rd ed. Philadelphia/New York: W.B. Saunders; 2010
2. Arnoczky SP, Warren RF. Microvasculature of the human meniscus. Am J Sports Med 1982;10(2):90–95
3. Clark CR, Ogden JA. Development of the menisci of the human knee joint. Morphological changes and their potential role in childhood meniscal injury. J Bone Joint Surg Am 1983;65(4):538–547
4. Weiss CB, Lundberg M, Hamberg P, DeHaven KE, Gillquist J. Non-operative treatment of meniscal tears. J Bone Joint Surg Am 1989;71(6):811–822
5. Talley MC, Grana WA. Treatment of partial meniscal tears identified during anterior cruciate ligament reconstruction with limited synovial abrasion. Arthroscopy 2000;16(1):6–10
6. Stone RG, Frewin PR, Gonzales S. Long-term assessment of arthroscopic meniscus repair: a two- to six-year follow-up study. Arthroscopy 1990;6(2):73–78
7. Greis PE, Bardana DD, Holmstrom MC, Burks RT. Meniscal injury: I. Basic science and evaluation. J Am Acad Orthop Surg 2002;10(3):168–176
8. DeHaven KE, Black KP, Griffiths HJ. Open meniscus repair. Technique and two to nine year results. Am J Sports Med 1989;17(6):788–795
9. DeHaven KE, Lohrer WA, Lovelock JE. Long-term results of open meniscal repair. Am J Sports Med 1995;23(5): 524–530
10. Anderson K, Marx RG, Hannafin J, Warren RF. Chondral injury following meniscal repair with a biodegradable implant. Arthroscopy 2000;16(7):749–753
11. Kurzweil PR, Tifford CD, Ignacio EM. Unsatisfactory clinical results of meniscal repair using the meniscus arrow. Arthroscopy 2005;21(8):905
12. Siebold R, Dehler C, Boes L, Ellermann A. Arthroscopic all-inside repair using the meniscus arrow: long-term clinical follow-up of 113 patients. Arthroscopy 2007;23(4):394–399
13. Cohen SB, Boyd L, Miller MD. Vascular risk associated with meniscal repair using Rapidloc versus FasT-Fix: comparison of two all-inside meniscal devices. J Knee Surg 2007;20(3): 235–240
14. Borden P, Nyland J, Caborn DN, Pienkowski D. Biomechanical comparison of the FasT-Fix meniscal repair suture system with vertical mattress sutures and meniscus arrows. Am J Sports Med 2003;31(3):374–378
15. Kocabey Y, Chang HC, Brand JC Jr, Nawab A, Nyland J, Caborn DN. A biomechanical comparison of the FasT-Fix meniscal repair suture system and the RapidLoc device in cadaver meniscus. Arthroscopy 2006;22(4):406–413
16. Mehta VM, Terry MA. Cyclic testing of 3 all-inside meniscal repair devices: a biomechanical analysis. Am J Sports Med 2009;37(12):2435–2439
17. Zantop T, Eggers AK, Musahl V, Weimann A, Petersen W. Cyclic testing of flexible all-inside meniscus suture anchors: biomechanical analysis. Am J Sports Med 2005;33(3):388–394
18. Zantop T, Eggers AK, Weimann A, Hassenpflug J, Petersen W. Initial fixation strength of flexible all-inside meniscus suture anchors in comparison to conventional suture technique and rigid anchors: biomechanical evaluation of new meniscus refixation systems. Am J Sports Med 2004; 32(4):863–869
19. Marzo JM, Gurske-DePerio J. Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. Am J Sports Med 2009;37(1):124–129
20. DeBerardino TM. Arthroscopically assisted meniscal allograft transplantation. Oper Tech Sports Med 2005; 13:227–232
21. Fairbank TJ. Knee joint changes after meniscectomy. J Bone Joint Surg Br 1948;30B(4):664–670
22. McNicholas MJ, Rowley DI, McGurty D, et al. Total meniscectomy in adolescence. A thirty-year follow-up. J Bone Joint Surg Br 2000;82(2):217–221
23. Burks RT, Metcalf MH, Metcalf RW. Fifteen-year follow-up of arthroscopic partial meniscectomy. Arthroscopy 1997; 13(6):673–679
24. Lee SJ, Aadalen KJ, Malaviya P, et al. Tibiofemoral contact mechanics after serial medial meniscectomies in the human cadaveric knee. Am J Sports Med 2006;34(8):1334–1344
25. Cannon WD Jr. Arthroscopic meniscal repair. Inside-out technique and results. Am J Knee Surg 1996;9(3):137–143
26. Johnson MJ, Lucas GL, Dusek JK, Henning CE. Isolated arthroscopic meniscal repair: a long-term outcome study (more than 10 years). Am J Sports Med 1999;27(1):44–49
27. Rubman MH, Noyes FR, Barber-Westin SD. Arthroscopic repair of meniscal tears that extend into the avascular zone. A review of 198 single and complex tears. Am J Sports Med 1998;26(1):87–95
28. Choi NH, Kim TH, Victoroff BN. Comparison of arthroscopic medial meniscal suture repair techniques: inside-out versus all-inside repair. Am J Sports Med 2009;37(11):2144–2150
29. Spindler KP, McCarty EC, Warren TA, Devin C, Connor JT. Prospective comparison of arthroscopic medial meniscal repair technique: inside-out suture versus entirely arthroscopic arrows. Am J Sports Med 2003;31(6):929–934
30. Post WR, Akers SR, Kish V. Load to failure of common meniscal repair techniques: effects of suture technique and suture material. Arthroscopy 1997;13(6):731–736
31. Rankin CC, Lintner DM, Noble PC, Paravic V, Greer E. A biomechanical analysis of meniscal repair techniques. Am J Sports Med 2002;30(4):492–497
32. Barber FA, Herbert MA, Richards DP. Load to failure testing of new meniscal repair devices. Arthroscopy 2004; 20(1):45–50
33. Arnoczky SP, Warren RF, Spivak JM. Meniscal repair using an exogenous fibrin clot. An experimental study in dogs. J Bone Joint Surg Am 1988;70(8):1209–1217
34. van Trommel MF, Simonian PT, Potter HG, Wickiewicz TL. Arthroscopic meniscal repair with fibrin clot of complete radial tears of the lateral meniscus in the avascular zone. Arthroscopy 1998;14(4):360–365