AUGMENTATION OF MENISCUS REPAIR

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Rates of healing following meniscus repair range from 63 to 91%. Meniscus tears in the well-vascularized periphery are able to mount a proper healing response, whereas tears in the avascular zone have limited healing capabilities. To increase healing rates, several techniques have been devised to enhance the healing of meniscal tears, especially those in avascular regions. This chapter reviews the techniques available for augmentation of meniscal repair, including vascular access channels, addition of fibrin clot, and microfracture of the intercondylar notch. Each of these techniques is designed to increase the vascular supply or induce blood and marrow elements at the site of meniscus repair, to increase the rate of meniscal healing.

KEY WORDS: meniscus repair, augmentation, fibrin clot, microfracture

There have been considerable technological advances in meniscus repair since Annandale performed the first repair on November 16, 1883.[1] A variety of meniscal repair techniques exist, including open repair, outside-in, inside-out, and all-inside techniques, all of which have shown successful meniscal healing. Depending on the technique and timing of repair, the reported rate of meniscal healing varies from 63 to 91%.[2-16]

With open repair techniques, DeHaven and co-workers[5] showed a survival rate of repaired menisci of 79% after 10 to 13 years. In addition, Muellner and co-workers[17] documented a survival rate of 91% with a follow-up of 13 years. Several studies have documented good results with inside-out repair techniques, ranging from 73 to 91%.[6,18-25] Similarly, with outside-in techniques, Morgan and co-workers[12] demonstrated that 65% of menisi were healed at second look arthroscopy. Plaesschaert and co-workers[26] and Mariani and co-workers[27] reported a 74% survival rate after 3.5 years and 77.3% clinically good results with an average follow-up of 28 months, respectively, using outside-in techniques. Recently, all-inside techniques have gained popularity because of their simplicity; however, the long term efficacy of these techniques has not been established.[28-34] Because of the biomechanical strength and ability to achieve anatomic repair, inside-out suturing remains the "gold standard" for meniscal repair.

Independent of the technique utilized, several factors have been identified that influence meniscal healing rates. These include rim width (distance of the tear from the menisco-synovial junction), anterior cruciate ligament (ACL) deficiency, concomitant ACL reconstruction, tear length, acute versus chronic tears, and side of the meniscus tear. Cannon[35] reported success rates of 90% with rim widths less than 2 mm. With rim lengths from 2 to 3.9 mm, success rates decreased to 74%, and with rim widths of 4 to 5 mm, success decreased to 50%.

The status of the ACL also has implications for meniscal healing rates. DeHaven and co-workers[4,5] documented higher failure rates for meniscal repairs in ACL-deficient knees. Concomitant ACL reconstruction has been shown to lead to higher rates of healing for meniscal repairs. Cannon[35] reported success in 83% of 92 patients when meniscus repair was performed in combination with ACL reconstruction. This compared favorably to their overall success rate of 75%. Other factors that significantly affect healing rates include tear length, time of repair after injury, and side of repair; failure rates are lower for tears less than 2 cm, tears repaired less than 8 weeks after injury, and tears of the lateral meniscus.[35]

Meniscus tears in the well-vascularized periphery benefit from a proper healing response, whereas tears in the poorly vascularized center have limited healing capabilities.[36,37] Central tears are challenging and do not reliably heal either spontaneously or with standard repair techniques.[38,39]

To improve healing rates, several techniques have been devised to enhance the biology of repair, especially in avascular regions. These innovative procedures can be divided into two different categories: primary repair and augmentation techniques. New primary repair techniques include the interposition of a synovial flap,[40-43] fibrin glue,[44,45] fibrin glue with endothelial cell growth factor,[46] cyanoacrylate glue,[47] platelet derived growth factor,[48] and laser stimulation.[49,50]

Augmentation techniques focus on enhancing mensiscal healing. There have been several studies, both clinical and basic science, showing increased healing of meniscal tears with the introduction of blood and marrow elements into the joint.[44,51,52] Therefore, most of these new techniques involve introducing intra-articular blood and marrow elements. These techniques include rasping the paramenis-

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cal synovium and rasping either side of the meniscus tear,[53] the creation of vascular channels,[54-58] placement of a fibrin clot,[51,59-61] and microfracture of the intercondylar notch.[62] The purpose of this article is to review several techniques believed to improve the healing rates of isolated mensicus tears.

BIOLOGY OF MENISCAL HEALING

Two distinct cell types have been identified embedded in an interlacing collagen network within a meniscus.[63] Surface cells are oval or fusiform, whereas deep cells are round or polygonal.[64,65] The morphology is suggestive of chondrocytes; however, the production of predominantly Type I collagen is more indicative of fibrochondrocytes.[66,67] Although the exact classification of these cells remains controversial, numerous studies have shown that the two cell types seem to respond uniquely to growth factors and media constituents which may be important in the healing response of the meniscus.[48,68,69]

An acute meniscus tear is infiltrated by inflammatory cells creating a vascularized fibrin clot. The fibrin clot acts as a scaffold and stimulus for cell proliferation including the infiltration by mesenchymal cells.[70] The clot becomes a fibrovascular scar by 10 weeks and undergoes further remodeling until the establishment of fibrocartilagenous tissue.[38] Organ culture studies have demonstrated that the cells in the avascular region do, in fact, possess an intrinsic healing response.[71] The meniscal fibrochondrocytes are capable of migrating in response to chemotactic and mitogenic stimuli, and they are able to proliferate and synthesize extracellular matrix in response to injury.[51,72,73]

Three potential sources of reparative cells have been identified. The early presence of fibroblasts in the clot-filled defects immediately adjacent to the meniscus suggest a possible direct contribution of meniscal cells to the repair process.[51] Synovial cells may be a source of pluripotential cells in the joint, thus contributing to the cellular repair response. The importance of these cells is demonstrated by studies showing the repopulation of acelluar connective-tissue autografts and allografts by synovial cells.[74-77] A third potential source of reparative cells is from the peripheral blood elements. An experimental study demonstrated the ability of mononuclear blood cells to transform and proliferate in vitro as fibroblasts.[78]

AUGMENTATION TECHNIQUES

The addition of blood, and specifically, marrow elements with pleuripotential stem cells are probably the most critical factors that enhance meniscal healing.[44] In the avascular zone of the meniscus, it is probably the absence of hematoma formation and its associated factors that limits meniscal healing.[79] In cases with concomitant ACL reconstruction, postoperative hemarthrosis may provide serum proteins, growth factors, and a fibrinous framework to the tear and promote healing. Experimental techniques to introduce intra-articular blood and marrow elements have been shown to increase the rate of meniscal healing.[44,51,52] Therefore, the common element in these augmentation techniques is the introduction of blood and marrow elements into the joint.

VASCULAR ACCESS CHANNELS

Experimental studies have shown that by connecting an avascular meniscal lesion to the peripheral blood supply via a vascular access channel that the healing cascade will ensue.[38] Gershuni and co-workers[55] and Zhang and co-workers[56] have both shown that preparation of vascular tunnels by trephination may promote the healing of the avascular tears in animal models. However, creation of the channel by trephination disrupts the peripheral circumferential fibers which may weaken the biomechanical properties of the meniscus.[38] Partial thickness trephination with suture repair of peripheral menisci produced partial or complete meniscal healing, whereas no healing was observed with peripheral menisci repaired with sutures alone.[56] Fox and co-workers[58] treated incomplete peripheral vertical meniscal tears with trephination and had 90% clinical success in 25 patients at 12 to 27 months follow-up.

VASCULAR ACCESS CHANNELS—OPERATIVE TECHNIQUE[58]

After a standard meniscus repair is performed, the meniscus is inspected. If a tourniquet is used, it is deflated to better assess the vascularity after trephination. An 18-gauge spinal needle, bent to maneuver between the articular surfaces, is used to puncture the meniscus from inside out, extending from the inner rim and substance of the tear into a peripherally vascular area in the capsule. The trephination is repeated until multiple bleeding puncture sites are observed.

FIBRIN CLOT

The fibrin clot has been evaluated scientifically and clinically, but the results are equivocal. In an animal study performed by Port and co-workers,[60] there was not a statistically significant enhancement of healing with the use of exogenous fibrin clot compared with vertically oriented sutures alone. The addition of cultured adherent autologous bone marrow-derived cells in conjunction with the fibrin clot did not enhance mensical healing. In dogs, Arnoczky and co-workers[51] demonstrated after the addition of a fibrin clot, there was reparative fibrocartilaginous material present in avascular meniscal lesions. This tissue is morphologically similar to the tissue seen in defects in the vascular area of the meniscus. Henning and co-workers[59] reported that the use of the fibrin clot decreased failures of isolated repairs from 61 to 8%, but Cannon observed only a modest reduction in failures from 60 to 42%.[35] Van Trommel and co-workers[61] had 3 of 5 patients with excellent healing at second look arthroscopy. Despite conflicting results, the addition of a fibrin clot may introduce factors that can stimulate a reparative response, especially in the avascular portion of the meniscus

FIBRIN CLOT—OPERATIVE TECHNIQUE[59,60]

A minimum of 30 mL of blood is obtained for the clot by sterile venous puncture. The blood is allowed to clot in a plastic or glass container, which is wetted with an Ancef (Smith Kline & French, Philadelphia, PA) irrigating solution and placed in a water bath at 37°. The newly formed

Fig 1. Several specimens of prepared fibrin clot are seen before placement into the site of meniscal repair.

clot is placed on a sponge and gently washed in the Ancef-containing saline irrigating solution. Next, the clot is placed between several sponges and gently compressed. Over the next 20 to 30 minutes (while the meniscus repair is being performed), the serum is absorbed by the sponges, leaving the firm clot (Fig 1). When ready for use, the clot is lifted off the sponge and loaded into a 2-mL glass syringe.[59]

Alternatively, 5 to 10 mL of venous blood is placed in a 20 or 60 mL plastic syringe to form a shorter, thicker clot, or a 10 mL syringe for a longer, thinner clot. A roughened 4 mm stirring rod is used to stir the blood while avoiding

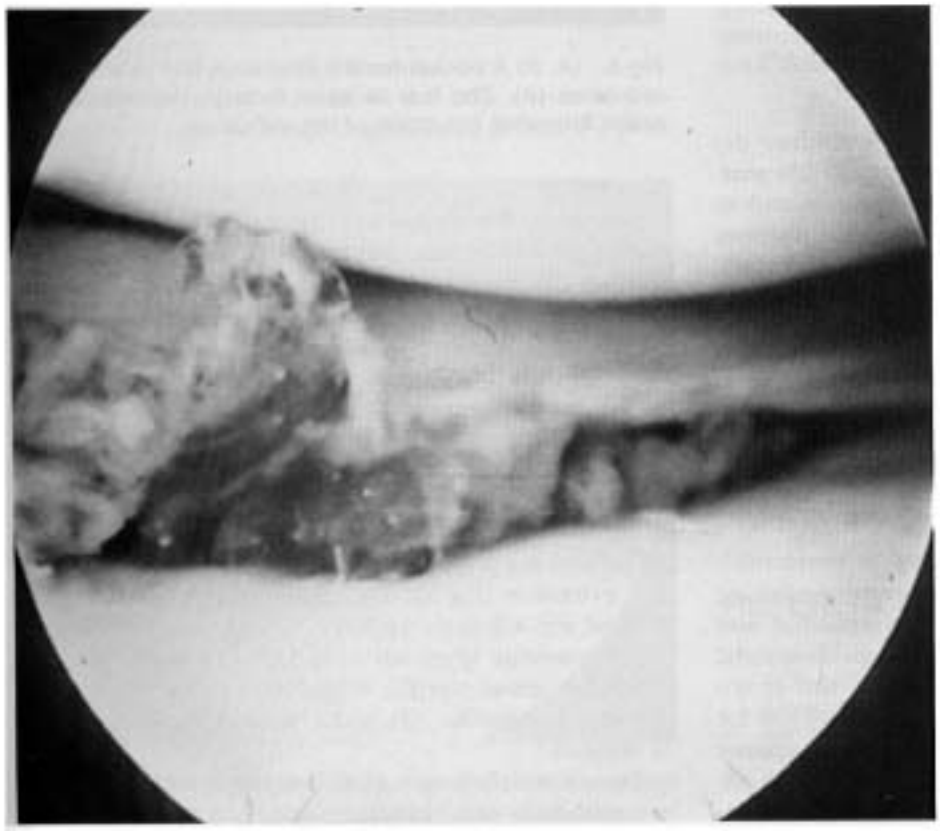


Fig 2. The fibrin clot is seen at the site of meniscus repair after the sutures are tied.

contacting the outer wall of the previously selected syringe. The nonstirring hand encircles the syringe to provide warmth the help speed coagulation. Within 3 to 5 minutes the clot forms and the rod is brought to the wall of the syringe. After 1 to 2 more minutes of a radial directed force while stirring, the rod is removed with the clot around it and placed onto a gauze sponge. This technique induces clot formation without the need for a water bath.[60]

A standard inside-out meniscal repair is performed, except for tying the sutures over the capsule. The knee is then suctioned to remove all irrigating solution. The blunt needle on the 2-mL syringe is passed through the accessory portals and directed into the seam of the meniscus tear. A slight bend in the blunt needle facilitates maneuvering of the needle into the tear. The needle is progressively moved through the space of the tear while the fibrin clot is injected. For most meniscal tears, 1.5 to 2 mL of clot is sufficient. The distractor is removed, and the sutures are tied around the clot, completing the meniscus repair (Fig 2).[59]

On the other hand, the authors have used plastic arthroscopic cannulas with the diaphragms removed, metal arthroscopic camera sheaths, and medium sized chest tubes to introduce the fibrin clot into the meniscal tear. Alternatively, it is relatively easy to introduce the clot through the ipsilateral portal after a suture has been tied gently around or passed through the clot. A meniscal repair needle and zone specific cannula is used to pass the other suture limb out the posteromedial or posterolateral meniscus repair incision. This suture limb is used as a traction suture to draw or pull the clot into the knee. A probe is used to position the clot before securing the meniscal repair sutures. When done under tourniquet, this maneuver can often be accomplished without the use of fluid (ie, a "dry knee").

MICROFRACTURE OF THE INTERCONDYLAR NOTCH

Microfracture of the intercondylar notch is another described technique.[62] It is a simple method to provide marrow elements to the site of meniscus repair to aid in meniscal healing at the time of repair. The technique does not require additional skills or novel arthroscopic devices. However, further basic science studies are critical to objectively evaluate the effects of marrow elements on the site of meniscus repair, as well as further clinical studies to validate the efficacy of this technique.

MICROFRACTURE OF THE INTERCONDYLAR NOTCH—OPERATIVE TECHNIQUE (AUTHORS' PREFERRED METHOD)[62]

A standard set-up for knee arthroscopy is performed. When a possible meniscus repair is to be performed, a leg holder is used to freely access the posteromedial and posterolateral aspect of the knee. A thorough diagnostic arthroscopy is performed. When a meniscus tear is encountered, it is assessed for reparability. The ideal tear for repair is a longitudinal, full-thickness tear that is greater than 1-cm and in the red-red or red-white zone (Fig 3A, B). In general, we do not repair meniscus tears in the white-white zone. The meniscus is prepared by gently rasping the edges of the tear. No excessive debridement is performed. We prefer to use an inside-out suture technique whenever possible. An accessory incision is made on the posteromedial or posterolateral aspect of the knee for suture retrieval. The appropriate zone specific cannula (Linvatec, Inc., Largo, FL) is used through the contralateral arthroscopy portal, and double-armed 2 to 0 Ethibond sutures (Ethicon, Somerville, NJ) are used to place vertical mattress sutures across the meniscus tear (Fig 4). The needles are retrieved through the accessory incision. Once all sutures are placed, the sutures are tied with the knee in full extension (Fig 5). The repair is then inspected and probed for adequate stability. Occasionally, for anterior horn meniscus tears, an outside-in technique, using an 18-gauge spinal needle, #0-polydioxanone suture (PDS, Ethicon, Somerville, NJ), and a "mulberry knot" technique is utilized.[81]

Once a satisfactory meniscal repair is performed, a 45° microfracture awl (Linvatec, Inc., Largo, FL) is placed

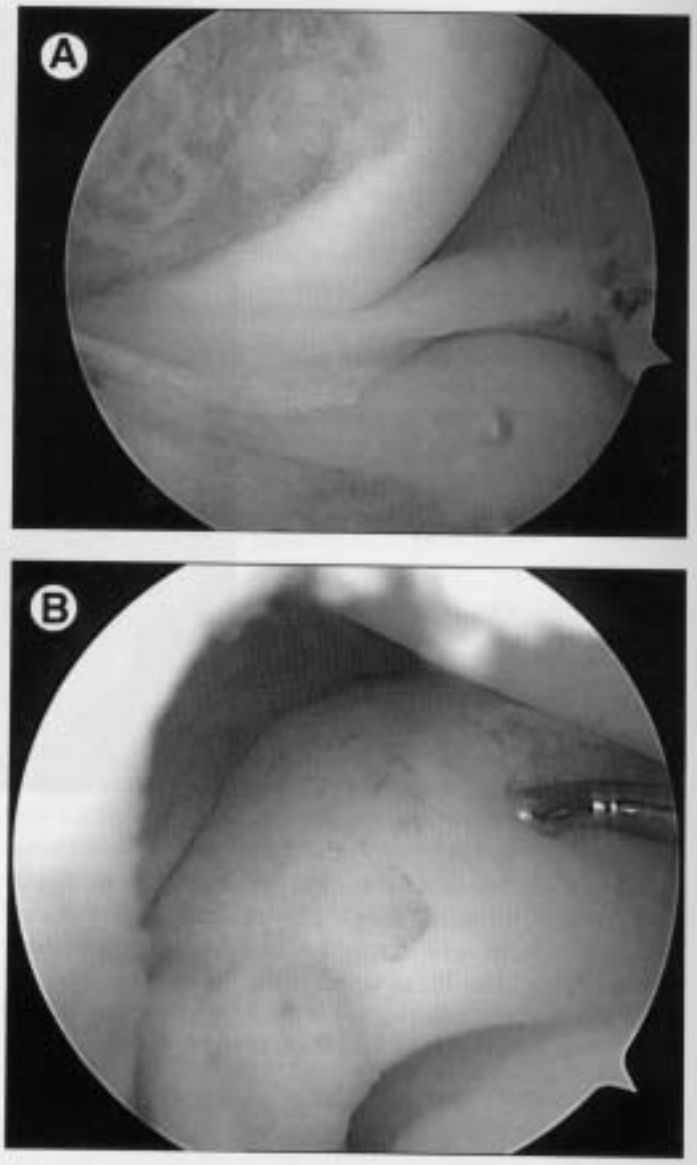


Fig 3. (A, B) A bucket-handle meniscus tear is seen before reduction (A). The tear is seen through the intercondylar notch following reduction of the meniscus.

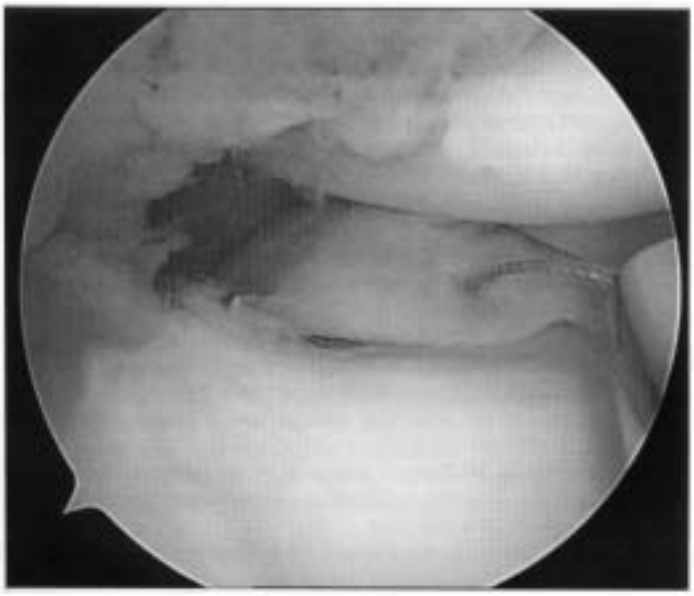


Fig 4. Inside-out suturing is performed to repair the tear.

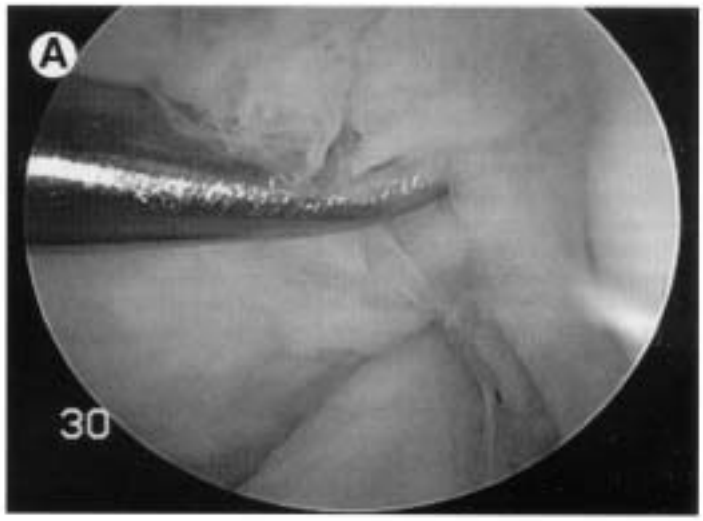
through the contralateral portal. The awl is repeatedly penetrated through the subchondral bone of the intercondylar notch at the PCL origin until marrow elements are seen to enter the joint. The flow of arthroscopic fluid is interrupted to better observe the marrow elements emanating from the microfracture holes (Fig 6A, B).

Postoperatively, a hinged knee brace is used. In the first 6 weeks, the patients are allowed to be weightbearing as tolerated with flexion from 0 to 90°. When the patients are nonweightbearing, flexion from 0 to 130° is allowed. After the first six weeks, full range of motion while weightbearing is allowed. Activity is progressed as tolerated. Return to full activity is permitted at 4 to 6 months postoperatively.

CONCLUSION

Numerous studies have revealed the importance of preserving the meniscus. These studies have shown the poor

Fig 5. The tear is seen following completion of the repair and after the sutures are tied outside the knee capsule.



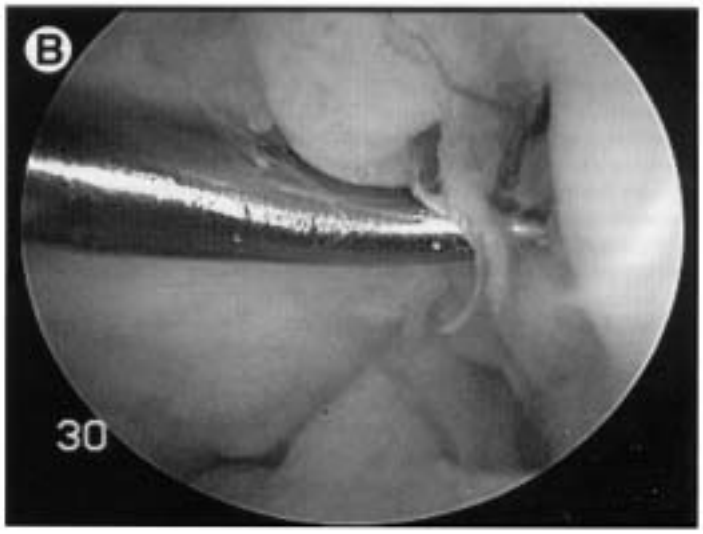


Fig 6. (A, B) The microfracture awl is used in the intercondylar notch along the lateral wall to make several holes in the bone (A). Blood and marrow elements are seen entering the joint through the site of the microfracture (B).

long-term prognosis after partial meniscectomy.[82-89] Alternatively, meniscal repair techniques have been very successful. Although healing rates decrease with lesions in the avascular zones, there have been several techniques developed to increase the rate of healing. These techniques have the common element of introducing blood and marrow elements into the joint. Our preferred technique is performing microfracture of the intercondylar notch. This is a relatively easy technique without additional arthroscopic hardware requirements; however, further studies are needed to critically evaluate the efficacy of this technique.

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