Meniscus Repair: Update on New Techniques

Nicholas A. Sgaglione, M.D.
Division of Sports Medicine, Department of Orthopaedic Surgery, North Shore University Hospital, and Orthopaedic Associates of Manhasset, Manhasset, New York

ABSTRACT
Increasing emphasis on the comprehensive reconstruction of the knee and on restoration of knee function after injury has heightened the interest in meniscus preservation. The approach to meniscal tears in the active individual emphasizes tissue repair over resection because meniscal tissue preservation has several potential advantages that improve the biomechanics and natural history of knee function over time. The technical approach to meniscal repair has significantly evolved in the last 10 years and continues to expand. Numerous techniques and multiple devices have been introduced and present the clinician with a vast array of surgical options. More recently, case reports documenting morbidities associated with the use of newer generation meniscal repair fixators have raised concerns regarding these devices and prompted recommendation that repair using suture may be preferred. An update on meniscus repair techniques is presented outlining and reviewing the current available procedures and implants including postoperative care, preliminary results, and complications. Technical pearls and pitfalls including optimal indications are reviewed for several of the repair methods as well as potential future directions in the approach to meniscal disease.

Key words: arthroscopic meniscal repair, new techniques, implant fixators

INTRODUCTION
The medial and lateral menisci have been shown to significantly contribute to optimal knee function by providing an essential biomechanical and structural role in joint load bearing and distribution, stability, congruence, as well as articular cartilage homeostasis and proprioception.1-6 It is well established that meniscal preservation in the younger active individual presenting with symptomatic meniscal disease is important.7-11 Furthermore, in those patients who are concurrently undergoing anterior cruciate ligament stabilization, articular cartilage resurfacing, or axial realignment osteotomies, the need to maintain meniscal tissue may be even greater.2,4,12,13 Recent advances in the approach to meniscal repair have heightened the interest in the numerous available surgical options. Evolving techniques, multiple devices, and improved understanding of the natural history of meniscal attrition and outcomes of meniscal repair prompt the need for a current review of the subject.

HISTORY
King first reported on meniscal disease in an animal model study in 1936 and found that in the canine meniscus, tears in the peripheral vascular zone had the capacity to heal.14 Despite this work, most clinicians advocated and performed meniscal resection until the 1970s, when the introduction and widespread embrace of arthroscopy and expanding research into meniscal vascular and ultrastructural anatomy and function began to be better understood. The increased emphasis on physical fitness and conditioning as well as the information and influence generated by the media spotlight on sports and injured athletes has prompted demand for both the preservation of knee function and a more predictable return to preinjury performance and stressful activity. The parallel emphasis on and evolution of the treatment of anterior cruciate ligament (ACL) deficiency and significant association of ACL injury and meniscal tears has further turned attention to the repair of meniscal tears.

Clinical reports of meniscal repair by Henning and longer-term follow-up data published by DeHaven supports the efficacy and success of both open and arthroscopic approaches to repair.15-18 Increasing work in the laboratory, in addition to patient follow-up data, has advanced the concept of meniscal preservation and ultimately prompted the development of improved meniscal repair devices.19-22 Various techniques have been described including open, arthroscopic-assisted, outside-in, inside-out, all-inside, suture-based, and implant or fixator based.16,21-24

Address correspondence and reprint requests to Nicholas A. Sgaglione, M.D., Orthopaedic Associates of Manhasset, 800 Community Drive, Manhasset, NY 11030, U.S.A. e-mail: nas@optonline.net


Volume 1, Issue 2

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.
INDICATIONS AND CONTRAINDICATIONS

The indications for meniscal repair have been expanding as a better understanding of pathophysiology, repair site healing, and biomechanical behavior and performance of various repair techniques and devices is achieved. Vertical longitudinal tears located in the red–red and red–white vascularized zones of the meniscal periphery are anatomically optimal for repair\(^{14,19}\) (Fig. 1). The indications and contraindications for meniscal repair are outlined in Table 1. Asymptomatic tears that are not clinically correlative, particularly in patients older than age 60 years, with associated articular cartilage degenerative arthritis are clearly not repaired. Patients, who after counseling regarding postoperative healing, activity restrictions, and repair failure rates, decide that resection is preferable, are not candidates for meniscal repair.

PREOPERATIVE PLANNING

Preoperative planning begins with the clinical diagnosis of meniscal tears. The history of trauma, hemorrhrosis in the presence of an ACL injury, associated joint-line pain, swelling, and mechanical symptoms of locking and catching are indicative of a meniscus tear. Physical examination findings include assessment of axial alignment, antalgia, posttraumatic loss of motion (particularly extension), pain with squatting in terminal flexion, focal joint-line point tenderness, pain with axial compression testing (in flexion and extension), palpable joint-line click, and effusion. Plain radiographs should be obtained in all cases and should include extension anterior/posterior and medial/lateral views as well as a notch and patella skyline view. In addition, weight-bearing \(45^\circ\) flexion posterior–anterior comparison views should be obtained in cases in which there is any suspicion of articular cartilage wear and to accurately assess joint-space narrowing. Routine magnetic resonance imaging is often not indicated in the presence of meniscal disease but may be useful in cases where other ligamentous, articular cartilage, or bony disorder (i.e., osteonecrosis) is suspected. When appropriate and comprehensive nonsurgical treatment fails and patient counseling and expectations and proper indications are addressed, surgical intervention is appropriate. More urgent operative intervention is appropriate in cases of displaced meniscal tears and associated locking.

SURGICAL TECHNIQUES

Preparation

The author’s preferred technique of meniscus repair is performed with the patient under local anesthesia with intravenous sedation on an outpatient basis at an ambulatory surgery center. Preoperative prophylactic intravenous antibiotics are not routinely given. When associated ACL reconstruction is carried out, then a femoral nerve regional block anesthesia is used with general endotracheal anesthesia or epidural anesthesia. A lateral post (Telos; Fallston, MD, U.S.A.) is preferred to apply valgus stress and open the medial joint for medial meniscal disease. If ACL reconstruction or articular cartilage procedures are to be performed, then the meniscal repair is

<table>
<thead>
<tr>
<th>TABLE 1. Indications and contraindications to meniscal repair</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indications</strong></td>
</tr>
<tr>
<td>Acute, symptomatic tears</td>
</tr>
<tr>
<td>Vertical, longitudinal tears</td>
</tr>
<tr>
<td>Peripheral, red-red/red-white tears</td>
</tr>
<tr>
<td>&gt; 7–10 millimeters (mm) in length</td>
</tr>
<tr>
<td>Unstable: &gt; 3 mm of excursion</td>
</tr>
<tr>
<td>Nondeformed, viable tissue</td>
</tr>
<tr>
<td>Concomitant reconstructive surgery: ACL or articular cartilage</td>
</tr>
<tr>
<td>procedures</td>
</tr>
<tr>
<td>Patient preferred</td>
</tr>
</tbody>
</table>
Meniscus Repair

carried out first, and it is the author’s preference to tie and secure the sutures prior to carrying out the ACL procedure.

The meniscal tear site is essentially identified as a site of suboptimal nonhealing tissue subject to compressive, tensile, and shear loads and is unable to adequately respond to those loads. Furthermore, the tear is located in an environment that is fluid filled and subject to motion in multiple planes. The goal of repair is to achieve optimal strength of fixation and load sharing until biologic healing is adequate for the native meniscal tissue to function under applied mechanical loads. Prior to obtaining fixation, the tear site must be assessed, measured, reduced, and debrided of nonvital tissue. It is then prepared and freshened to stimulate and promote peripheral native tissue and to contribute to healing. Stabilization is then obtained and fixation accomplished either with suturing techniques or placement of a fixation repair device. Meniscal repair may be supplemented (as needed) with autologous substances in the form of fibrin clot to improve the healing environment.

The technique of meniscal repair begins with identifying whether the tear is repairable. The site, length, excursion or stability, reducibility, and viability in terms of tissue deformation and extent of damage and fraying are all assessed. Medial meniscal repairs are performed with valgus stress applied against a lateral post in varying degrees of flexion while lateral repairs are performed with the patient’s leg in a figure-of-four configuration. Depending upon whether suture or implants or fixators are used, then a contralateral approach to the posterior horns is used (i.e., posterior horn medial meniscal tears are approached from a contralateral inferolateral portal with the suture repair device).

After assessment confirms that the tear is repairable, if the patient will not require an associated ACL reconstruction, then a fibrin clot technique is planned for and immediate autologous blood is requested and obtained by the attending anesthesiologist (see Repair Methods: Fibrin Clot Technique). The tear is reduced and the tear edges are geometrically matched to ensure that an appropriate reduction can be obtained. It is particularly important to reduce displaced and unstable bucket handle tears. A provisional reduction can be obtained and facilitated using an 18-gauge spinal needle inserted either in an inside-out or outside-in direction.

Preparation of the tear site is begun by gently debriding both the meniscal tear site and edges as well as the peripheral meniscal–capsular junction using a motorized shaver blade. A low-profile meniscal rasp can also be used and is helpful in preparing the peripheral junction. Vascular access channels can be created using the spinal needle or a meniscal trephine. Care must be exercised to avoid overly aggressive penetration of the peripheral meniscal circumferential tissue band and the body of the meniscus fragment to avoid further injuring the tissue and producing stress risers. Trephination and abrasion are particularly important in cases where a repair is performed in less vascularized zones. After preparation is complete, the specific and preferred repair technique(s) are selected and carried out. Depending upon the method and device used, the length and vector geometry of the tear site should be assessed to provisionally select the number of sutures or fixators that will be needed and also the length of the devices that may be needed as far as the size of the patient, size of the meniscus, distance of the tear from the periphery and capsule, and technique used.

Repair Methods: Open Technique

Open repair of the menisci, popularized by DeHaven, is less commonly performed in the era of arthroscopy. However, in cases of extraarticular ligament reconstruction in which capsular reefing may be concurrently performed, especially medially or in cases in which an associated miniarthroscopy may be performed (articular cartilage or meniscal allograft transplantation), open suturing of meniscal tears is useful. Nonabsorbable 2-0 or 0 interrupted suture is used to repair the meniscus tear to adjacent meniscal tissue or the peripheral capsule.

Repair Methods: Arthroscopic Outside–In Technique

Reported in the literature by Warren and more recently by Rodeo, arthroscopic outside-in meniscal repair can be carried out using several methods. The outside-in repair technique is particularly useful for repairing anterior horn or mid-third body tears. After identification and assessment of the tear, a series of 18-gauge spinal needles placed 3 to 5 mm apart or a corresponding suture-passing needle system are passed from outside to inside through the tear, perforating the inner (or superior femoral) and outer (or inferior tibial) surfaces. An absorbable monofilament suture may be used such as polydioxanone (Ethicon, Somerville, NJ, U.S.A.) and the individual suture strands may be pulled out of the arthroscopic portal and a “mulberry” knot tied, which is then withdrawn back into the joint and tensioned at and up to the meniscal tear site. More recently various suture materials can be used in combination with dedicated outside-in meniscal repair instrumentation. Several nonabsorbable suture configurations can be placed including horizontal and vertical mattress patterns, depending on the needle passage using a wire loop retriever and placement of the suture knot in an extracapsular location. The outside-out repair technique requires that a small skin incision be made surrounding the sutures that allows dissection around the sutures and down to the capsule,
and which then allows the appropriate tensioning of the sutures down to the capsule and subsequent knot tying (Figs. 2A and 2B).

**Repair Methods: Arthroscopic Inside-Out Technique**

Popularized by Henning, who began performing the technique in 1980, inside-out meniscus repair has enjoyed the most clinical experience and documentation in the literature. It has been referred to as the “gold standard” against which more recent techniques have been compared. The method in general is performed using a series of anatomically matched and contoured (right and left knee) arthroscopic cannulae that are placed through the arthroscopic portals and up to the tear site, usually from a contralateral portal. This method requires attention to the antegrade direction and vector of the cannula and subsequent needle passage to safely repair the tear and protect the neurovascular structures. Extra-long suture needles are then passed though the cannulae across the tear and out the posteromedial or posterolateral aspect of the knee. Depending upon whether a single- or double-lumen cannula system is used, vertical, horizontal, and oblique sutures patterns can be achieved. It is important to safely “capture” and retrieve the needles through accessory posteromedial and posterolateral incisions that are preferably made prior to passage of the needles. The accessory incisions are made with the knee in 90° of flexion at the level of the joint line, extending one third above the joint but more importantly two thirds below the joint. A curved retractor is inserted anterior to and deep to the corresponding side gastrocnemius, which facilitates protection of the adjacent soft tissues and allows the passing needles to be safely “bounced” off of the retractor and out the incision as they exit the capsule. The posteromedial incision is made just posterior to the medial collateral ligament above the level of the sartorius, which is retracted posteriorly with the sartorial branch of the saphenous nerve (although anatomic variation may exist) The dissection is continued anterior to the semimembranosus and deep to the medial head of the gastrocnemius muscle belly sweeping the posteromedial capsule. The posterolateral incision is similarly made in flexion, which posteriorizes the peroneal nerve. The interval used posterolaterally is just posterior to the lateral collateral ligament and the iliotibial band, staying above and anterior to the biceps femoris tendon and muscle fibers of the short head of the biceps tendon. Dissection is continued deep and anterior to the lateral head of the gastrocnemius muscle belly, sweeping the posterolateral capsule clear. Upon completion of the placement of a series of sutures through the tear site, the sutures are tied to the corresponding adjacent suture limb over the capsule while arthroscopically viewing the tensioning and seating of the sutures on the meniscal tissue. The medial meniscal repair sutures are tied with the knee in 20° of flexion, while the lateral repair sutures are tied down with the knee in 90° of flexion, and it is the author’s preference to tension and tie the sutures prior to performing concomitant procedures such as ACL reconstruction.

**Repair Methods: All-Arthroscopic Fixator Technique**

Recently, multiple meniscal repair devices have become available that enable an all-arthroscopic approach to stabilizing tears. These devices have made meniscal repair truly arthroscopic, easier, quicker, associated with less
surgical dissection (no accessory incisions), and with less pain and less need for operating room assistance. There are advantages and disadvantages to the use of implant fixators and inside-out suture techniques (Table 2). Various devices have been introduced since the Bionx Meniscal Arrow (Bionx Implants Inc., Blue Bell, PA, U.S.A.) was released in 1996 (Table 3).

Arthroscopic meniscal repair fixators are in general, based on a reverse-barbed fish-hook design and are made of bioabsorbable materials composed of various amounts of polylactic and or polyglycolic acid copolymers. Several proprietary manufacturing and processing methods exist in which the polymer materials may be extruded and machined versus injection molded. The different polymer and copolymer configurations including whether the microstructure is crystalline or amorphous as well as the various processing methods can impart varying biomechanical and structural properties as well as hydrolysis, degradation, and resorption profiles to the implants.

The technique of repairing meniscal tears using fixators is similar for most devices in that after preparation of the tear site, and potentially provisional reduction, the tear distance from the periphery is assessed and measured, which allows selection of the appropriately sized fixator length. The fixator(s) are then inserted perpendicular to the tear (vertical, longitudinal tears clearly represent the most optimal tear pattern for repair) and across the tear bridging the two meniscal fragments and stabilizing them with the device held in place by the reverse barbs or cross bar on the shaft. It is essential that there be enough meniscal tissue on both sides of the tear in order for the device to function optimally, and it follows that peripheral capsular detachments and meniscal allografts are not necessarily indications for fixator repairs. Each device is then inserted at 3- to 5-mm intervals. An important pearl is that extreme care must be taken to ensure that the fixator head is seated flush or countersunk to the surrounding surface of the meniscus to reduce the chance of articular cartilage injury (Fig. 3, Table 4).

**TABLE 2. Advantages and disadvantages of inside-out suture and fixator techniques**

<table>
<thead>
<tr>
<th>Advantages of suture and fixator techniques</th>
<th>Implant fixators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inside-out suture</strong></td>
<td><strong>Implant fixators</strong></td>
</tr>
<tr>
<td>Strength: 70 to 113 Newtons</td>
<td>Reduced strength</td>
</tr>
<tr>
<td>Compression across tear site</td>
<td>Limited compression</td>
</tr>
<tr>
<td>Versatility: vertical suture patterns</td>
<td>Variable resorption profile</td>
</tr>
<tr>
<td>Experience: clinically documented</td>
<td>Foreign body reaction</td>
</tr>
<tr>
<td>Safety: outcomes published</td>
<td>Brittle/breakage</td>
</tr>
<tr>
<td><strong>Disadvantages of suture and fixator techniques</strong></td>
<td>Bioresorbable</td>
</tr>
<tr>
<td><strong>Inside-out suture</strong></td>
<td><strong>Implant fixators</strong></td>
</tr>
<tr>
<td>Time consuming</td>
<td>Arthrofibrosis</td>
</tr>
<tr>
<td>Accessory incision</td>
<td>More dissection/more pain</td>
</tr>
<tr>
<td>OR assistant necessary</td>
<td>Needle stick risks</td>
</tr>
<tr>
<td>Needle stick risks</td>
<td>More dissection/more pain</td>
</tr>
<tr>
<td>Arthrofibrosis</td>
<td>Arthrofibrosis</td>
</tr>
</tbody>
</table>

**Repair Methods: Fibrin Clot Technique**

The technique of insertion of an exogenous autologous fibrin clot is based on the concept of promotion of tear site healing by introducing blood-associated biologic factors including platelets that may act as chemical mediators for tissue repair and as well as an adherent mechanical scaffold. This may be particularly effective in the knee where motion, meniscal excursion, and joint fluid can all contribute to reduction in repair tissue formation and maturation. Various methods for preparation and insertion of a fibrin clot have been reported.15,19,27 The author’s preferred technique used in cases of isolated repair (since in cases of concomitant ACL reconstruction the hemarthrosis that accompanies the tunnel drilling may serve to produce an environment sufficient for healing) is to obtain 30 to 50 cm³ of blood from the patient’s intravenous site and then steriley transfer it to a glass container and stir it with a sintered glass rod. After formation of the clot, the rest of the blood is decanted off and the clot is blotted dry. Upon completion of the repair and with the arthroscopic fluid turned down, the clot is inserted under arthroscopic visualization using a grasper within a 5-mm diameter cannula with its diaphragm removed and placed across the portal.22 The clot is then inserted under the repair site adjacent to the tibial surface of the tear. No specific sutures are used to anchor the clot, although other authors have reported on techniques to suture the fibrin clot into the repair.15

**FIXATOR DEVICES: FIRST GENERATION**

**Meniscus Arrow**

The Meniscus Arrow (Bionx, Blue Bell, PA, U.S.A.), released in 1996, was the first arthroscopic fixator device to be popularly used, and a greater experience with this particular device exists.28 The original design was “T” shaped with a 1.1-mm-diameter shaft of three lengths (10, 13, and 16 mm) and a 4-mm-long “T” head. The shafts of the device each have reverse barbs at right angles to the ‘T’ head and 90° offset to each other with the 10-mm device being fully barbed while the 13-mm and 16-mm devices each have 10 mm of barbs and 3-mm and 6-mm lengths of smooth shaft, respectively (Fig. 4). The Arrow can be inserted manually using a curved and variable insertion cannulae system or a mechanical de-
TABLE 3. Meniscal repair fixator devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Sizes</th>
<th>Material</th>
<th>Resorption</th>
<th>Strength* load to failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTOUR ARROW</td>
<td>10, 13 16 mm length × 1.1 mm diameter 0.7 mm head</td>
<td>Self-Reinforced Copolymer 80% PLLA 20% PDLA</td>
<td>12–24 months</td>
<td>33.6 N (Result for 13 mm 1st Generation Device)</td>
<td>Redesigned Lower Profile Head, Fully Barbed Shaft, Copolymer &amp; CrossBow Inserter</td>
</tr>
<tr>
<td>SD Sorb STAPLE</td>
<td>7 mm (10 mm) with 4 mm suture</td>
<td>82% PLLA 18% PGA</td>
<td>15 months</td>
<td>31.4 N</td>
<td>Lower Profile Design Pending</td>
</tr>
<tr>
<td>BIODINGER</td>
<td>10, 13 16 mm × 1.25 mm diameter</td>
<td>Injection-molded PLLA</td>
<td>36 months</td>
<td>56.6 N (13 mm)</td>
<td>New Hornet cannulated insertion device</td>
</tr>
<tr>
<td>FASTENER (Mitek, Westwood, MA)</td>
<td>6 and 8 mm</td>
<td>Prolene (polypropylene) or PDS (polydioxanone)</td>
<td>PDS 6–16 weeks</td>
<td>30 N (8 mm Prolene)</td>
<td>12, 24 and 34° curved inserters</td>
</tr>
<tr>
<td>CLEARFIX SCREW (Mitek)</td>
<td>10 mm by 2.0 mm diameter</td>
<td>PLLA</td>
<td>18 months</td>
<td>32.5 N</td>
<td>Cannulated with variable thread pitch</td>
</tr>
<tr>
<td>DART (Arthrex, Naples, FL)</td>
<td>10, 12, 14 mm by 1.3 mm diameter</td>
<td>Amorphous PDLA Copolymer</td>
<td>9 months</td>
<td>Not tested</td>
<td>Double reverse barbs: Flexible. New Dart Stick</td>
</tr>
<tr>
<td>STAPLE (Arthrotek, Warsaw, IN)</td>
<td>11 and 13 mm</td>
<td>Lactosorb 82% PLLA 18% PGA</td>
<td>12 months</td>
<td>27 N</td>
<td>Double pronged fixation</td>
</tr>
<tr>
<td>Fast-Fix (Smith &amp; Nephew, Andover, MA)</td>
<td>(2) 5 mm suture anchors</td>
<td>PLLA or Polyacetate and 0—nonabsorbable suture</td>
<td>NA</td>
<td>Not tested</td>
<td>Second Generation: vertical mattress suture possible</td>
</tr>
<tr>
<td>RAPIDLOC (Mitek)</td>
<td>(2) suture anchors</td>
<td>PLLA Tophat (POS) &amp; backstop Ethibond or Panacryl suture</td>
<td>NA</td>
<td>Not tested</td>
<td>Second Generation: Suture device Compression possible</td>
</tr>
</tbody>
</table>

*Study reference: 52

vice known as the “Crossbow” with multiple implant devices preloaded in a magazine. Material composition of the original Arrow design was self-reinforced polymerized levorotatory polylactic acid (PLLA). Specifically the levorotatory “L” stereoisomer preparation, which is the biologically active form, is highly crystalline and has been estimated to have a resorption profile of 36 to 60 months. As of late 2000, the Arrow composition was changed to a 96% PLLA combined with 4% of the polylactic acid dextrorotatory “D” stereoisomer con-
The easier the fixator insertion technique, the more essential the need to prepare the tear site. Reduce the tear to avoid gapping, ruffling and lift-up and begin inserting fixators from the center of the tear out to avoid “dog ears.” Use of an outside-in temporary stay suture aids in holding displaced bucket-handle tears reduced in place. Pay attention to the inner 3-dimensional taper of the meniscus when inserting the implants to avoid cutting or troughing the tissue. Place the devices perpendicular to the tear using accessory portals as needed. Configure the size of the patient, meniscal structure, tear site and implant length to maximize strength of the device mechanics and limit native tissue irritation. Ensure that the device is countersunk or flush with the surrounding meniscus. Avoid overstuffing the tissue with fixators; place every 3 to 5 mm apart. Consider hybrid repair constructs. Range knee and arthroscopically view the repair. Consider fibrin clot or capsular abrasion in isolated repairs to promote healing. Adjust and individualize postoperative rehabilitation.

**FIG. 4.** Original and updated Bionx Contour Meniscal Arrow.

**TABLE 4. Pearls on use of meniscal fixators**

| The easier the fixator insertion technique, the more essential the need to prepare the tear site. Reduce the tear to avoid gapping, ruffling and lift-up and begin inserting fixators from the center of the tear out to avoid “dog ears.” Use of an outside-in temporary stay suture aids in holding displaced bucket-handle tears reduced in place. Pay attention to the inner 3-dimensional taper of the meniscus when inserting the implants to avoid cutting or troughing the tissue. Place the devices perpendicular to the tear using accessory portals as needed. Configure the size of the patient, meniscal structure, tear site and implant length to maximize strength of the device mechanics and limit native tissue irritation. Ensure that the device is countersunk or flush with the surrounding meniscus. Avoid overstuffing the tissue with fixators; place every 3 to 5 mm apart. Consider hybrid repair constructs. Range knee and arthroscopically view the repair. Consider fibrin clot or capsular abrasion in isolated repairs to promote healing. Adjust and individualize postoperative rehabilitation. |

---

figuration (PDLLA). The PDLLA configuration is more amorphous and possesses different degradation and mechanical properties. The 96/4 copolymer imparts a quicker resorption time to the device. Further developments introduced in 2002 have included changing the copolymer to a more flexible and amorphous 80% PLLA and 20% PDLLA, changing the 1.1-mm-thick “T” head to a lower profile rounded 0.7-mm head (Contour Arrow), adding barbs to the entire length of the shaft and introducing a second-generation mechanical Crossbow inserter. These changes have been introduced in response to issues of retained PLLA fragments not being more quickly resorbed, the brittle and hard character of self-reinforced PLLA, reports of chondral injury from prominent fixator heads, and suboptimal fixation strength profiles (Fig. 4).
SD Sorb Staple
This device, released by Surgical Dynamics (Norwalk, CT, U.S.A.) in 1997, consists of two barbed 7-mm fixation posts comprising 82% PLLA/18% PGA linked by a 4-mm braided nonabsorbable suture. The copolymer is reportedly resorbed in approximately 15 months. The device provides two points of fixation and is inserted using a preloaded manual device or a multifire gun. New updated design modifications include longer 10-mm fixation posts, and redesigned inserter head with a lower profile insertion system with precurved tips.

Biostinger
The Linvatec Company (Largo, FL, U.S.A.) introduced the Biostinger in 1998 as the first cannulated device with a lower profile head. This fixator, which is violet colored, making it easier to visualize against tissue, is 1.25 mm in diameter and contains four rows of reverse barbs on all sides of the shaft and is available in 10-, 13-, and 16-mm lengths (Fig. 5A). It comprises 100% PLLA with a resorption profile of 36 to 60 months. Three generations of insertion devices have been introduced with the Biostinger, and improvements in design have recently produced the “Hornet” disposable insertion system, which comes in three dedicated sizes corresponding to the three available implant sizes, which come preloaded on the color-coded inserters (Fig. 5B).

Fastener
Mitek (Westwood, MA, U.S.A.) introduced the Mitek Meniscal Repair System in 1998, which included the Fastener, a “T/J”-shaped fixator device available in two sizes—6 and 8 mm—and two materials, nonabsorbable Prolene and absorbable PDS/polydioxyanone (Ethicon), which has a resorption profile of 6 to 16 weeks. The Fastener can be inserted with a curved cannulae system that comes in three angled tips: 12, 27, and 34°. The Fastener is unique in that it is one of the few fixator devices that can be used for repair of peripheral meniscal tears since its design allows for deployment of the leading crosslimb of the device outside the periphery of the meniscus and on the other side of the capsule.

Clearfix Screw
The Clearfix Screw, also available from Mitek and introduced in 1998, is a 2.0-mm-diameter × 10-mm-long headless screw-in design that allows for countersinking and has a 0.3-mm variable pitch thread that theoretically adds compression across the tear site. The device is made of PLLA with a resorption profile of up to 18 months. It is inserted using a cannulated delivery needle-guided system.

Dart
Arthrex (Naples, FL, U.S.A.) released the meniscus repair Dart in 1999 as a lower profile headless 1.3-mm-diameter × 10-mm-long implant that can be countersunk. The barb configuration is one of a double-reverse design, thereby proving improved pull-through as well as pull-out strength and potentially limiting device migration (Fig. 6).

The Dart is placed across the tear site in at least a pair construct functioning as two points of fixation. The device is comprised of an amorphous PLLA/PDLLA copolymer which imparts more flexibility to the fixator and is associated with a 36-week resorption profile. It is inserted using either a manual or spring-loaded delivery system and curved cannulae. Updated technique modifications include the use of a preloaded manual insertion device, the Dart Stick, which facilitates placement of the implants.
Staple
The Meniscal Staple (Arthrotek, Warsaw, IN, U.S.A.) was released in 1999 and delivers fixation via a double-pronged barbed staple available in 11- and 13-mm lengths. The device can be inserted with either a manual curved cannulae system or a mechanical gun. The Meniscal Staple is composed of an 82% PLLA and 18% PGA copolymer with a resorption profile reported to be on the order of 12 months.

Fixation Devices: Second Generation
The array of available fixators that can be labeled “first generation” all share a similar design. Because of early case reports of problems of foreign body synovitis, retained and painful fragments, and chondral scuffing and injury, as well as published laboratory studies indicating that these devices provide inferior fixation strength compared to vertical mattress-suture configurations, improved designs have been sought. In response to these concerns and in the interest of reducing morbidities and increasing biomechanical strength, second-generation devices have been released recently that incorporate all-arthroscopic techniques and hybrid bioabsorbable fixator/anchor and suture constructs.

RapidLoc
Mitek released the RapidLoc in 2001 as a meniscal repair system that incorporates both suture and fixator. The device is an integrated needle delivery system consisting of a leading 5 × 2.5-mm PLLA (PDS as of 2003) “backstop” anchor with attached suture that is inserted across the tear site and then extracapsularly. In sequence, a second attached PLLA anchor (with overlying pre-tied, self-sliding, integrated knot) known as a “tophat” is cinched down on the suture towards the backstop and right up to the tear site, thereby compressing the tear between the two anchors connected by the suture. The “tophat,” which is 4.5 mm wide and 0.25 mm thick, is then seated intraarticularly on the femoral side of the meniscus, and compression across the tear site can be obtained by using an arthroscopic knot pusher to further seat the knot (Fig. 7). The delivery needles are available in straight as well as 12° and 27° curved configurations, and the suture is available in nonabsorbable 2–0 Ethibond or extended resorption Panacryl suture (Ethicon).

FasT-Fix
In 2001, Smith and Nephew (Andover, MA, U.S.A.) released the FasT-Fix Meniscal Repair System. Some of the initial design was in part an expansion of the T-Fix meniscal repair system introduced by Smith and Nephew in 1994 in that a 5-mm polyacetal anchor bar with attached nonabsorbable suture is inserted in an integrated...
needle delivery system across the tear site and is anchored extracapsularly. The T-Fix system required arthroscopic knot tying and each anchor was individually placed. The FaST-Fix system incorporates a design that includes two 5-mm polyacetal anchors with attached 0 nonabsorbable braided synthetic polyester suture integrated in sequence with a preloaded, pretied, self-sliding knot and delivered in an arthroscopic 16.5-gauge insertion needle. The integrated delivery needle is available in a straight or a 22-degree curve. The system includes a split-sheath insertion cannula and separate knot pusher/suture cutter. The variable positioning choices for the needle insertion allow for arthroscopic placement of vertical mattress suture configurations and in addition, the use of suture placed across the tear site and anchored extracapsularly introduces compression across the tear. In 2002, design advances included the release of the FaST-Fix system, improved and sharper trochar tipped delivery needles, waxed-tip suture for easier threading, and more ergonomic and easier-to-use needle delivery insertion handpieces and split-sheath cannulae (Fig. 8).

**POSTOPERATIVE PROTOCOLS**

Postoperative management begins in the operating room with attention to postoperative pain control. Intraarticular bupivacaine mixed with extended-acting morphine is injected into the knee, and nonsteroidal antiinflammatory drugs (NSAIDs) are given intravenously. Postoperative cryotherapy and extended-acting analgesics and NSAIDs are prescribed along with immediate supervised physical therapy beginning postoperative day 1. Patients are instructed to take one aspirin a day as tolerated for prophylaxis against thromboembolic disorders.

The author’s preferred postoperative regimen does not deviate much from the protocol used after ACL reconstruction (using patellar tendon autografts) and is similarly followed for isolated meniscal repairs. Patients are placed in a postoperative brace or knee immobilizer in the operating room locked in extension. The immobilizer is used for comfort and to facilitate ambulation and transfers. It is discontinued when the patient has adequate leg control and is comfortable without it or at about 3 weeks. Weight is allowed in extension initially on crutches and then advanced as comfort allows, with full weight bearing encouraged when antalgia and effusion subsides and quadriceps firing is adequate, usually at 3 to 4 weeks. Range of motion 0 to 90° is encouraged immediately on postoperative day 1 (or the night of surgery if an associated ACL is performed as the patients in those cases are placed in a continuous passive motion machine in the recovery room set 0 to 90°). Progression of motion, particularly in terminal flexion, is encouraged depending upon the repair site, size, geometry, and strength. Large, deformed, bucket-handle tears extending through to the posterior horns are progressed more slowly during the first 2 months from the standpoint of terminal flexion and loading and squats beyond 90°. A functional rehabilitation protocol is followed progressing each patient dependent upon comfort with range of motion, restoration of strength, and ultimately ability to perform agility and functional as well as sport-specific drills. Return to sports is usually at 4 to 6 months when appropriate functional goals are reached and the patient no longer has point tenderness over the repair site.

**COMPLICATIONS**

In a review of data obtained through surveying members of the Arthroscopy Association of North America, Small reported an overall complication rate incidence of 2.4% in an for meniscal repair. This number was noted to be higher in a series reported by Austin and Sherman, in which an overall complication rate of 18% was noted to be associated with arthroscopic meniscal repair and a 7% incidence of saphenous neuropathy and 6% incidence of

![FIG. 8. Second-generation device: Fast-Fix.](image-url)
Meniscus Repair

arthrofibrosis. It is important to point out that the series was collected from patients undergoing surgery between 1984 and 1991 and may represent an earlier experience with suture repair techniques. In a subsequent prospective series of 8,741 arthroscopies performed by “experienced” arthroscopists, the incidence of saphenous neuropathy after a meniscal repair was 0.01% and the incidence of complications after meniscal repair (with both inside-out and outside-in techniques) was actually lower (1.29%) than for arthroscopic meniscectomy (1.69%). More recently, numerous case reports have been published outlining the problems that can be encountered with the use of arthroscopic fixators including pull-out and pull-through device failure with migration and breakage, cystic hematoma, foreign body reaction, and chondral injury. Intraoperative and postoperative complications after meniscal repair surgery can be classified as major and minor.

Major complications can be considered any significant untoward event that requires a subsequent surgical procedure, hospitalization, or significantly changes the postoperative course of the patient. These include common peroneal, tibial, and saphenous nerve injuries and popliteal artery and vein injuries. Deep infection, postoperative septic arthritis and arthrofibrosis, sympathetically mediated Type II complex regional pain syndromes, and mechanical abrasion of the chondral surfaces from prominent implants associated with chondral injury are also included. Thromboembolic disease including deep vein thrombosis and pulmonary embolism as well as failure of meniscal healing with persistent clinical symptoms of pain, swelling, and mechanical symptoms are considered major complications. Minor complications can be considered self-limiting, transient, and not associated with any extended or permanent disability and include superficial infection, transient foreign body reactions and synovitis, retained and/or migrating and painful fixator fragments, and transient soft tissue inflammation.

RESULTS

Numerous studies have been directed towards mechanical testing of various suture materials and patterns of suture placement. More recently, work has been performed to assess the behavior of repair devices ex vivo and to compare suture to different available fixator devices. It is important to point out that multiple factors can affect the laboratory data, including the various polymer material properties, size, geometry, design, and degradation kinetics. Mechanical testing of pull-out, pull-through, repair site strength, load to failure, cyclic testing, hydrolysis time effects, and animal model versus human cadaveric aged specimens all can introduce confounders that make result interpretation more complex. In general, vertical mattress suture configurations perform more optimally than horizontal patterns. In addition, most fixators are associated with less mechanical strength than suture, specifically vertical mattress non-absorbable suture.

Outcomes after meniscal repair have been published for the various discussed techniques. DeHaven reported 100% retrieval of 33 cases with an average age of 18.9 years, at average 10.9-year follow-up (range: 10.1–13) treated with open meniscal repair and noted a 79% long-term survival rate. Radiographic analysis revealed that 85% of patients noted to have a successful repair outcome had no significant degenerative changes compared to 43% of patients with recurrent meniscal tearing and presumably repair failure. It was concluded that increased re-tear rates were noted in knees that were ACL deficient.

Early reports of results after the inside-out repair technique were reported by Henning in 260 repairs performed in 240 patients, with an average age of 22 years at an average follow-up of almost 2 years. Concomitant ACL reconstruction was performed in 80% of cases. The results indicated that 62% of repairs were healed on arthroscopic second look or by arthrogram compared to 17% incompletely healed and 21% not healed. Of note, based on clinical and subjective evaluation, 92% of cases were stable and 80% returned to active sports.

In a comprehensive review of 117 consecutive inside-out repairs, by Cannon, 90 cases were reported on; 68 repairs with concomitant ACL reconstruction and 22 isolated repairs. The average age was of the patients was 27 years. Overall rate of clinical success was 82%, with 93% of the ACL-associated cases successful compared to 50% of the isolated cases. Several conclusions were discussed including that clinical success tends to be better than arthroscopic assessed (anatomic) and arthrogram-assessed success. In cases in which rim width was up to 2 mm, success was 96% compared to 50% in case of rim widths out to 4 to 5 mm. Tear lengths of less than 2 cm were associated with success in 94%, whereas in cases greater than 4 cm, this dropped to 50%. Lateral repairs (70–100%) fared better than medial (34–73%). Age of the patient did not seem to matter, and patients with tears less than 8 weeks old were associated with 88% success compared to 79% in the “chronic” tears.

Outside-in technique results have been published by Rodeo, who found that in 90 patients average 25 years at an average follow-up of 46 months (range: 36–89 months), an overall 87% had a successful outcome. Failure was noted in 38% of the unstable knees, 15% of the stable knees, and 5% of the ACL reconstructed knees. The author concluded that the results after this
technique were comparable to results reported after inside-in repairs and pointed out that it is especially useful for repairing tears in the anterior horn region.

The more recent introduction of meniscal repair fixators has narrowed the outcome conclusions, and long-term published data remain limited. Jones et al. reported on a retrospective series of 38 patients undergoing meniscal repair with the Meniscal Arrow (Bionx) at 29.7-month follow-up. In 21 cases in which concomitant ACL reconstruction was performed, no clinical failures (defined as reoperation) were noted, whereas in 17 isolated repair cases, success was noted in 93%. The authors noted, however, that there was a 31.6% incidence of transient local soft-tissue inflammation related to device migration, length, prominence, and possible reaction to the resorbable materials. Petsche reported on a single surgeon’s experience with the Meniscus Arrows in 29 patients with an average age of 29 years available for follow-up at an average of 24 months after meniscal repair surgery. He found that there was a 7% incidence of failure, and in five cases mild subcutaneous irritation was noted that resolved in all cases within 3 to 7 months. In a published prospective report of 37 patients, average age 26.8 years, undergoing repair with the Mitek Meniscal Fastener (Mitek, Norwood, Massachusetts) at 1 year follow-up, there were 5 reruptures and 32 cases in which the procedure was interpreted as successful. The authors conclude that the failure rate was comparable to that of other studies in the literature and that the healing rate was high with few associated complications.

The author’s own unpublished results include a consecutive series of 109 meniscal repairs performed using an all-arthroscopic hybrid technique. The technique used was a hybrid combination and use of two devices, the Meniscal Arrow (Bionx) and the T-Fix system (Smith and Nephew Endoscopy), a first-generation device comprising nonabsorbable braided synthetic suture and a 5-mm polyacetal suture bar that is inserted and anchored beyond the tear extracapsularly. Arthroscopic knots are then tied to stabilize the tear site between the 3- to 5-mm insertion spacing of two of the implants. The study group was followed prospectively, with the average age 28 years (range: 15-49 years) and the average follow-up 3.2 years (range 2 to 4.4 years). The Meniscal Arrow was used exclusively for the repair in 55% of cases, whereas Arrows and the T-Fix were used in 45% of cases. The decision to select which cases were treated with the hybridized approach was not randomized but rather was based on the geometry and extent of the tear, tissue viability, and stability of the repair site. An associated ACL reconstruction was performed in 72 cases (60%), whereas an isolated repair was performed in 37 cases (40%). All isolated repairs were treated with an autologous fibrin clot technique. All patients received uniform postoperative care with 4 weeks of bracing in extension beginning with immediate range of motion 0 to 90° increasing beyond that at 4 weeks and partial weight-bearing on crutches for 4 weeks. Return to sports or stressful activity was advised in all cases after the 6 months. Result analysis revealed that no difference was noted at outcome between the Arrow alone group compared to the hybrid group. The overall failure rate, defined as the need to return for meniscal surgery, was 5.5%, with the isolated repair cases noted to have four failures (10.8%), whereas in the ACL reconstructed cases, there was a failure rate of 2.7% (two cases). No significant differences were noted between these groups. Several conclusions were drawn, including that satisfactory success could be obtained with an all-arthroscopic technique, that hybridized methods that incorporate suture and fixators may improve clinical results, and that isolated repair outcomes can approach the results noted with repair in association with ACL surgery.

In conclusion, review of most published study results reveals that clinical success after meniscal repair is comparable whether open, inside-out, outside-in, or all-arthroscopic fixator methods are used. In all studies, those cases of meniscal repair that are performed in conjunction with an ACL reconstruction clearly are associated with a higher rate of healing and more optimal clinical success than cases of isolated meniscal repair. This may be due to several factors including the release of marrow elements from osseous tunnel drilling that promote healing, the pain associated with a more complex surgery that “slows down” the patient postoperatively, thereby protecting the repair and the effect of ligamentous stabilization of the knee. There appears to be a significant potential for transient soft-tissue inflammation associated with some of the fixator devices; however, as more clinical experience is accrued and as the devices and polymer materials improve, these problems may become reduced.

**SUMMARY**

Meniscal repair in select active individuals with repairable meniscal tears should be performed whenever indications are met and appropriate patient counseling regarding outcomes is addressed. Far more meniscal resections will nonetheless be carried out compared to meniscal repairs. As the techniques and devices continue to improve, the decision to select one technique or techniques over another should ultimately be based on the sound evaluation of and experience associated with a particular device and its safety and potential efficacy. Surgeon preference and comfort with what works wins out over certain learning curve issues. Overall indica-
tions for the use of one technique over another may be dependent also on the types of tear that are repaired. In general, meniscal fixators and implants should be used for vertical, longitudinal red–white tears that are not peripheral detachments and are associated with at least a 2- to 3-mm rim width to provide optimal barb–tissue contact. Inside-out or outside-in suture may be best used for repair of more complex tear patterns or less vascular tears with less optimal tissue viability or with significant deformity or deformation as seen in large displaced bucket-handle tears. In addition, in cases of peripheral capsular detachment of the meniscus or in repairing meniscal allografts, suture should be used. Outside-in techniques may be particularly useful in cases of anterior horn, mid one-third tears, or in radial tears that extend to the periphery (Table 5).

The future remains bright, as on the horizon, developments in the area of polymer science will continue to provide better resorbable devices that will have safer and more bioinert degradation profiles that are more biologically specific to meniscal tissue and the temporal profiles of meniscal healing. The use of biologic and/or non-biologic adhesives may prove to be promising, and initial work using amphibian-derived adhesives for treatment of meniscal tears in a large-animal model has demonstrated optimal mechanical strength and sealant characteristics. (Zoltan S. Meniscus repair using frog glue. Presented at the 68th Annual Meeting of the American Academy of Orthopaedic Surgeons Specialty Day Meeting of the American Orthopaedic Society for Sports Medicine, San Francisco, CA, 2001). Laboratory work in the area of growth factors may provide a platform in which repair devices may soon have incorporated within them bioactive factors and anabolic polypeptides. Through control of dosing, delivery, and release mechanisms, these factors may promote and enhance healing, thereby speeding up recovery and simplifying postoperative protocols. Eventually, these methods may extend and expand the indications for repair to avascular tear sites. Much work is being done in the area of tissue engineering and molecular genetics. Gene-enhanced methods of repairing meniscal tears are being worked on in the laboratory with the use of genes virally transferred to transfected fibrochondrocytes that are expanded in culture and produce catabolic agents such as insulin growth factor (Grande D. Gene enhanced tissue engineering repair of the meniscus. Presented at the 27th Annual Meeting of the American Orthopaedic Society for Sports Medicine, Keystone, CO, 2001). The cells or tissue construct are then implanted into the tear site defects to promote healing. The use of biologic extracellular matrices such as porcine small intestine submucosa to promote a meniscal healing response through angiogenesis and host cell proliferation is also being investigated. Finally, the use of photodynamic devices in conjunction with reactive chemical “dyes” has been reported and may be applied to areas of meniscal disease to covalently bond collagen fibers and produce a seal and/or reduce propagation of a tear through “tissue welding” (Jackson R, personal communication, 2002). These methods represent the potential future of orthopedics and may one day be a reality in clinical orthopedic practice.

### TABLE 5. Repair techniques indications

<table>
<thead>
<tr>
<th>Outside-in sutures</th>
<th>Anterior horn tears</th>
<th>Mid-third tears</th>
<th>Radial tears</th>
<th>Complex tears</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside-out sutures</td>
<td>Posterior horn tears</td>
<td>Mid-third tears</td>
<td>Displaced bucket-handle tears</td>
<td>Peripheral capsular tears</td>
</tr>
<tr>
<td>Fixator implants</td>
<td>Posterior horn tears</td>
<td>Tears with &gt; 2 to 3 mm rim width</td>
<td>Vertical, longitudinal tears</td>
<td>Posterior horn tears</td>
</tr>
<tr>
<td>Suture-based and devices</td>
<td>(2ND generation devices)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CONCLUSIONS

1. As the emphasis on comprehensive knee reconstruction increases, and the importance of meniscal structure and function is further documented, the indications for meniscal repair are expanding.
2. Meniscal repair techniques have continued to significantly evolve, and numerous implant fixators are available that have improved surgical options.
3. Outside-in, inside-out, and all arthroscopic fixator methods remain popular and are each associated with advantages and disadvantages and successful outcomes. Hybridized techniques may be used to combine the best of all techniques in select cases.
4. Second-generation implant devices that combine suture and arthroscopic implant anchors may result in a repair construct that affords compression across the tear, thereby improving tensile strength.
5. Postoperative care should be individualized depending upon the tear site, size, tissue viability, repair strength, and device used.
6. The future of meniscal repair may include biologic manipulation of healing through bioactive peptides and growth factors that may be delivered via incorporation in repair sutures or fixator implants. Gene-enhanced tissue engineering may have a role in the approach to meniscal disease.
REFERENCES

38. Albrecht-Olsen P, Kristensen G. The meniscus tack versus


