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Meniscus Repair and Transplantation: A Comprehensive Update

The menisci provide several vital mechanical functions in the knee joint. They act as a spacer between the femoral condyle and tibial plateau and, when there are no compressive weight-bearing loads across the joint, limit contact between the articular surfaces. The menisci provide shock absorption to the knee joint during walking and are believed to assist in overall lubrication of the articular surfaces.[36,75] Following meniscectomy, the tibiofemoral contact area decreases by approximately 50%, while the contact forces increase 2-fold to 3-fold.[2,32,74] Meniscectomy frequently leads to irreparable joint damage, including articular cartilage degeneration, flattening of articular surfaces, and subchondral bone sclerosis.[26,49,66,79] Poor long-term clinical results have been reported by many investigators following partial and total meniscectomy.[3,34,54,57,58,61]

Preservation of meniscal tissue and function is paramount for long-term joint function, especially in younger patients who are athletically active. Since early reports of meniscus repair in the 1980s, considerable attention has been made to improve surgical techniques, understand appropriate indications, and enhance postoperative rehabilitation to restore normal joint function. While early studies focused on repair of simple longitudinal tears located in the periphery or outer one-third region of the meniscus, many studies have now been published on the outcome of repair of complex multiplanar tears that extend into the central third avascular region, and have reported encouraging success rates.[40]

Unfortunately, not all meniscus tears can be repaired, especially if considerable tissue damage has occurred. In appropriate patients, meniscus transplantation offers the potential to restore partial load-bearing meniscus function, decrease symptoms, and provide chondroprotective effects.[20,73,77] Transplantation of human menisci is no longer considered experimental, as over 30 clinical studies involving hundreds of patients have been published.[41] While the results of this operation vary, studies continue to justify the procedure in young patients who have undergone meniscectomy and have pain or articular cartilage damage in the meniscectomized tibiofemoral compartment.

In the 5 years since our last update on this topic in the *JOSPT*,[22] further longer-term data have been published supporting both meniscus repair[30,48,62] and meniscus transplantation.[63,69,73,76,77] The operative techniques and rehabilitation programs remain relatively similar, as do the indications and contraindications. Newer magnetic resonance imaging (MRI) techniques, including use of a 3-T scanner with cartilage-sensitive pulse sequences and T2 mapping, have provid-

SYNOPSIS: Preservation of meniscal tissue is paramount for long-term joint function, especially in younger patients who are athletically active. Many studies have reported encouraging results following repair of meniscus tears for both simple longitudinal tears located in the periphery and complex multiplanar tears that extend into the central third avascular region. This operation is usually indicated in active patients who have tibiofemoral joint line pain and are less than 50 years of age. However, not all meniscus tears are repairable, especially if considerable damage has occurred. In select patients, meniscus transplantation may restore partial load-bearing meniscus function, decrease symptoms, and provide chondroprotective effects. The initial postoperative goal after both meniscus repair and transplantation is to prevent excessive weight bearing, as high compressive and shear forces can disrupt healing meniscus repair sites and transplants. Immediate knee motion and muscle strengthening are initiated the day after surgery. Variations are built into the rehabilitation protocol according to the type, location, and size of the meniscus repair, if concomitant procedures are performed, and if articular cartilage damage is present. Meniscus repairs located in the periphery heal rapidly, whereas complex multiplanar repairs tend to heal more slowly and require greater caution. The authors have reported the efficacy of the rehabilitation programs and the results of meniscus repair and transplantation in many studies. *J Orthop Sports Phys Ther 2012;42(3):274-290, Epub 4 September 2011. doi:10.2519/jospt.2012.3588*

KEY WORDS: *knee rehabilitation, meniscus repair, meniscus transplant*

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TABLE 1 Indications and Contraindications for Meniscus Repair

Indications
• Meniscus tear with tibiofemoral joint line pain
• Patients younger than 50 years of age or patients in their fifties who are athletically active
• Concurrent knee ligament reconstruction or osteotomy
• Meniscus tear reducible, good tissue integrity, normal position in the joint once repaired
• Peripheral single longitudinal tears: red-red, 1 plane; reparable in all cases, high success rates
• Middle-third region: red-white (vascular supply present) or white-white (no blood supply); often reparable with reasonable success rates
• Outer-third and middle-third regions, longitudinal, radial, horizontal tears: red-white, 1 plane; often reparable
Contraindications
• Meniscus tears located in inner-third region
• Chronic degenerative tears in which the tissue is of poor quality and not amenable to suture repair
• Longitudinal tears less than 10 mm in length
• Incomplete radial tears that do not extend into the outer-third region
• Patients older than 60 years of age
• Patients unwilling to follow postoperative rehabilitation program

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ed advanced, noninvasive insight into the ultrastructure of hyaline cartilage. This allows detection of early degenerative changes before discernible loss of cartilage thickness is visible on conventional MRI. Use of this technology allows for a better assessment of the chondroprotective effects of these operations and the integrity of the repair site or transplant tissue.

CLINICAL EVALUATION

A thorough history is taken and questionnaires are used to rate symptoms, functional limitations, sports and occupational activity levels, and patient perception of the overall knee condition according to the Cincinnati Knee Rating System.[6] A comprehensive knee examination is performed that includes assessment of knee motion, patellofemoral indices, tibiofemoral pain and crepitus, muscle strength, ligament subluxation tests, and gait abnormalities. The presence of tibiofemoral joint line pain on joint palpation is a primary indicator of a meniscus tear. Other clinical signs include pain on forced flexion, obvious meniscal displacement (such as popping, clicking, or catching) during joint compression and flexion and extension, lack of full extension, and a positive McMurray test.[33] The clinical examination may reveal tenderness on palpation at the posterolateral aspect of the joint, at the anatomic site of the popliteomeniscal attachments. The McMurray test is performed in maximum flexion, progressing from maximum external rotation to internal rotation, then back to external rotation. With maximum internal rotation, this test may produce a lateral, palpable snapping sensation, representing an anterior subluxation of the posterior horn of the lateral meniscus.

In all patients, radiographs are taken during the initial examination. These include an anteroposterior view of both knees in full extension, a lateral view at 45° of flexion, and an axial view of the patellofemoral joint. The anteroposterior and lateral radiographs are used for sizing assessment for meniscus allografts.[41] The tibiofemoral joint spaces (medial and lateral) are assessed with weight-bearing posteroanterior (PA) views taken at 45° of knee flexion. A tibiofemoral joint space of at least 2 mm on standing PA views is required for meniscus transplantation. Axial lower-limb alignment is measured using full standing, hip-knee-ankle weight-bearing radiographs in knees that demonstrate varus or valgus alignment on physical examination. Varus or valgus malalignment is also a contraindication to meniscus transplantation (unless corrected with a high tibial or femoral osteotomy). MRI is obtained using a proton-density-weighted, high-resolution, fast spin-echo sequence[18,50] to determine the status of the articular cartilage and menisci. As viewed on MRI, advanced knee joint arthrosis, with flattening of the femoral condyle, concavity of the tibial plateau, and osteophytes, is a contraindication for meniscus transplantation.

MENISCUS REPAIR

Indications

The indications and contraindications for meniscus repair are shown in **TABLE 1** and have been described in detail elsewhere.[40,44] Candidates are active patients who have tibiofemoral joint line pain and usually less than 50 years of age, or in their fifties and athletically active.[62] The patient must be willing to follow the rehabilitation program, including protected weight bearing for up to 6 weeks. Those in whom complex tears are repaired must agree to avoid strenuous activities and deep knee flexion for 4 to 6 months to prevent tearing and failure of the repair. Meniscus tears are classified at arthroscopy according to location, type of tear, and integrity and damage to meniscal tissue and the meniscus attachment sites. This classification and a meticulous arthroscopic inspection of the tear site determine if a tear is repairable. The meniscus tissue should appear nearly normal, with no secondary tears or fragmentation. A complex multiplanar tear located in the middle-third region or in multiple planes may have a success rate of approximately 50%, and the repair of these more difficult tears is usually performed in young patients in an attempt to preserve some meniscal function.

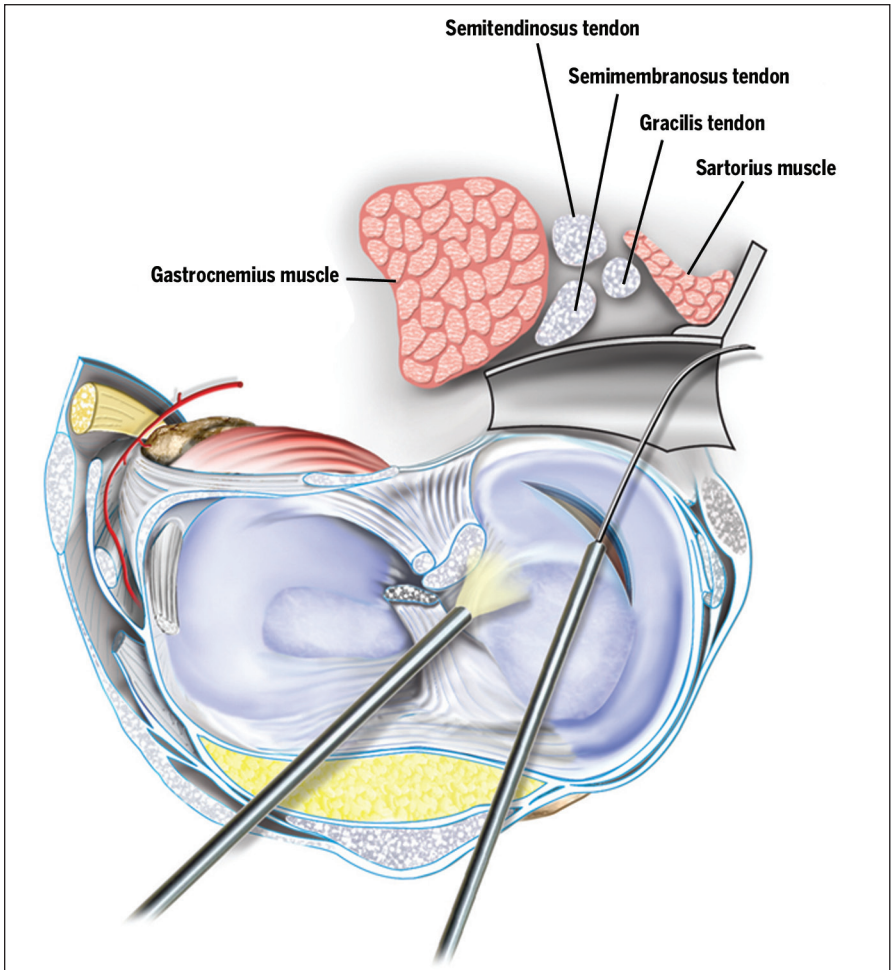

FIGURE 1. Cross-section showing popliteal retractor between the posterior capsule and medial gastrocnemius for a medial meniscus repair. The suture cannula is placed through the lateral or medial portal, with care taken to angle the needle away from the neurovascular structures. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus tears: diagnosis, repair techniques, clinical outcomes, 733-771, Copyright Saunders, 2009.[40]

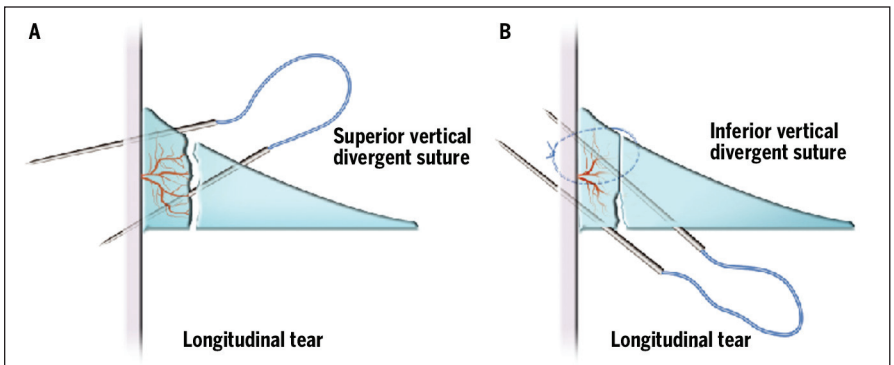

FIGURE 2. Double-stacked vertical suture pattern used in the repair of longitudinal meniscus tears. (A) The superior sutures are placed first to close the superior gap and to reduce the meniscus to its bed. (B) Then, the inferior suture is placed through the tear to close the inferior gap. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus tears: diagnosis, repair techniques, clinical outcomes, 733-771, Copyright Saunders, 2009.[40]

Operative Techniques

Several studies have analyzed the biomechanical properties of suture techniques and meniscus repair devices.[5,9,17,35,78,80,81] Vertical sutures are superior to both horizontal sutures and meniscus arrows in mean load-to-failure values.[4,16,52,78] The superior strength of vertical sutures is hypothesized to be due to the perpendicular orientation to the circumferential collagen bundles of the meniscus.[52]

We have previously described the operative techniques for meniscus repair of various types of tears in detail.[40] Diagnostic arthroscopy is first performed and the meniscus tear analyzed according to its location, type, and size. The meniscus tissue and synovial junction are rasped to stimulate bleeding at the meniscus-synovial border. Loose, unstable meniscus fragments are removed. Our preferred inside-out repair procedure uses multiple 2-0 braided polyester nonabsorbable sutures (Ti-cron; Davis & Geck Co, Danbury, CT; or Ethibond; Ethicon Inc, Somerville, NJ). The neurovascular structures are protected throughout the procedure with the appropriate exposure and a Henning retractor (**FIGURE 1**).

The location of sutures is dependent on the tear pattern. For single longitudinal tears, vertical divergent sutures are placed at 3- to 4-mm intervals along the length of the tear in alternating fashion, first on the superior surface to reduce the meniscus, then on the inferior surface to close the inferior tear (**FIGURE 2**).The sutures are brought out through the accessory incision and tied directly over the posterior meniscal attachment and capsule. The tension in each suture is confirmed arthroscopically after the knot is tied (**FIGURE 3**). Double-longitudinal meniscus tears require an additional set of sutures (**FIGURE 4**). The peripheral tear is repaired in the same manner as a single longitudinal tear with superior and inferior sutures. The longitudinal tear located in the middle body is repaired with 2 or 3 additional superior and inferior sutures.

Radial tears are repaired with horizontal sutures placed at 2- to 4-mm in-

tervals along the tear site (**FIGURE 5**). The inner sutures are placed first and securely tied, followed by sutures located in the periphery. Three to four sutures are used on the superior surface and 1 or 2 sutures are used on the inferior surface. Flap tears require 2 sets of sutures (**FIGURE 6**). Tension sutures are inserted first through the flap and then into the intact meniscal rim to anchor and reduce the flap into its anatomic bed. With the meniscus reduced, the remaining tear is repaired in the same fashion as a longitudinal tear, with superior and inferior vertical divergent sutures.

MENISCUS TRANSPLANTATION

Indications

The indications and contraindications for meniscus transplantation are shown in **TABLE 2**.[41] The results of this operation are more favorable when it is performed before the onset of advanced tibiofemoral joint arthritis. Normal axial alignment and a stable joint are required, as untreated varus lower-limb malalignment and anterior cruciate ligament (ACL) deficiency increase the risk of transplant failure.[12,67,68] At least 2 mm of tibiofemoral joint space should be visible on 45° weight-bearing PA radiographs. Prophylactic meniscus transplantation is not recommended in asymptomatic patients who do not have articular cartilage damage, because predictable long-term success rates are not available.

Operative Techniques

We have previously described in detail the operative techniques for lateral and medial meniscus transplantation.[41] The central bone-bridge technique is our preferred method for both transplants, because this procedure maintains the meniscus and bone in normal anatomic attachments and secures the meniscus in the desired position in the knee joint. However, in some cases, medial meniscus transplantation is accomplished using 2 bone tunnels.[41] The decision is made after the initial operative exposure and measurement of the anteroposterior and mediolateral dimensions required for the transplant. The central bone-bridge procedure is selected if the surgeon determines that the transplant will fit in the proper position adjacent to the ACL tibial attachment without overhang over the medial tibia and that the attachment locations are anatomically correct. If the transplant must be adjusted to either fit to the medial tibial plateau (by attaching the anterior horn placement further laterally) or to avoid compromising the ACL tibial attachment, then the 2-tunnel technique is used.

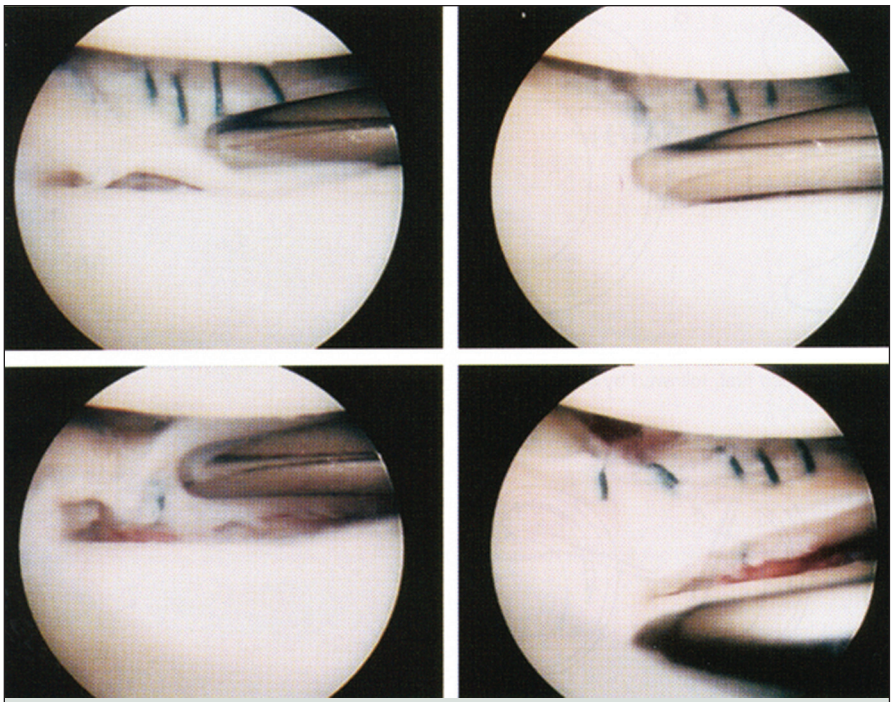

FIGURE 3. A longitudinal meniscus tear site demonstrating some fragmentation inferiorly. This tear required multiple superior and inferior vertical divergent sutures to achieve an anatomic reduction. The final version of this paper has been published in *Am J Sports Med*, 30, 2002 by SAGE Publications Ltd, All rights reserved. © 2002.[37]

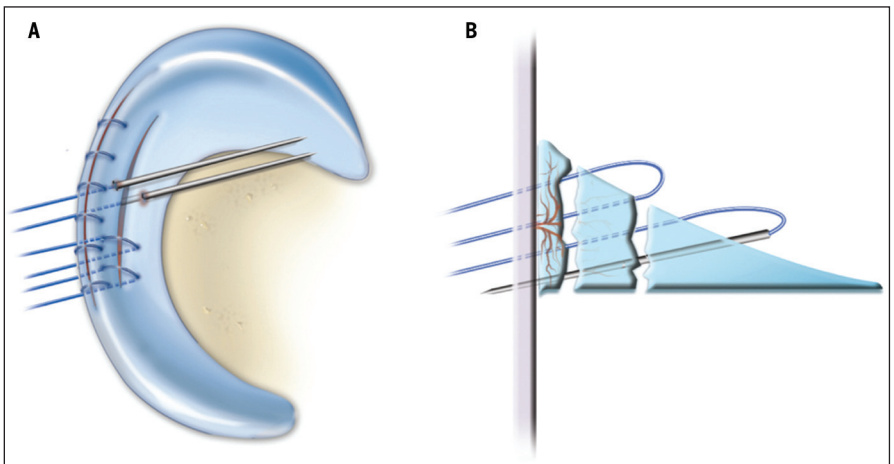

FIGURE 4. Double-stacked repair technique for double longitudinal tears. (A) The peripheral tear is repaired first with superior and inferior vertical divergent sutures, followed by (B) repair of the inner tear in the same fashion. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus tears: diagnosis, repair techniques, clinical outcomes, 733-771, Copyright Saunders, 2009.[40]

A variety of allograft sterilization techniques are available, including irradiation, cryopreservation, proprietary chemicals, and fresh-frozen. We have used all types of sterilization techniques in our clinical studies. At present, no scientific data exist to recommend one over another. Others have discussed the implications of different graft-processing methods, allograft-harvesting techniques, and disease testing.[7,14,70,71]

The patient is placed in a supine position on the operating room table, with a tourniquet applied with a leg holder, and the table adjusted to allow 90° of knee flexion. After examination under anesthesia, diagnostic arthroscopy confirms the preoperative diagnosis and articular cartilage changes. A meniscus bed of 3 mm is retained when possible, except at the popliteal tendon region, where the native meniscus rim is removed. The meniscus bed and adjacent synovium are rasped to aid in revascularization of the transplant.

For lateral meniscus transplants, a limited 3-cm lateral arthrotomy is made just adjacent to the patellar tendon and a second 3-cm posterolateral incision is made just behind the fibular collateral ligament.[40] A popliteal retractor is placed directly behind the lateral meniscus bed and anterior to the lateral gastrocnemius muscle. The width of the transplant is determined as described elsewhere.[41] A rectangular bone slot is prepared at the anterior and posterior meniscus tibial attachment sites to match the dimensions of the prepared transplant. The anterior and posterior horns of the transplant are placed into their normal attachment locations, adjacent to the ACL. The transplant is inserted into the slot and the bone portion of the graft is seated against the posterior bone buttress to achieve correct anterior-to-posterior placement of the attachment sites (**FIGURE 7A**). A vertical suture in the posterior meniscus body is passed posteriorly to provide tension and facilitate transplant placement. The suture is tied later in the procedure. The knee is flexed, extended, and rotated to confirm that correct placement of the transplant has been obtained. Sutures are placed into the anterior one third of the meniscus, attaching it to the prepared meniscus rim under direct visualization. Two sutures are placed retrograde into the tibial slot over the central bone bridge and tied to a tibial post. The arthrotomy is closed, and the inside-out meniscal repair completed with multiple vertical divergent sutures (**FIGURE 7B**).

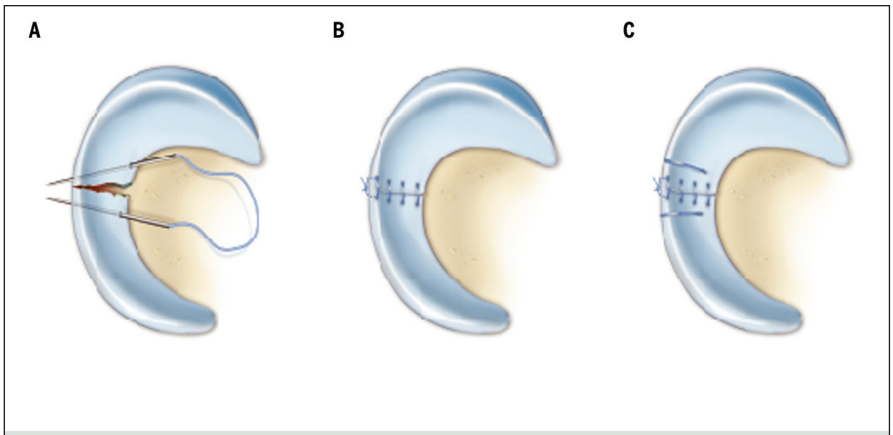

FIGURE 5. Repair technique for radial meniscus tears. (A) The inner sutures are placed first, followed by (B) the peripheral sutures. The first suture needle is placed midway through the meniscus body and then used to apply a circumferential tension to reduce the tear gap, and is then advanced through the posterior meniscus bed. The second suture needle is placed in a similar manner. This reduces the radial gap, allowing subsequent sutures to be placed. Usually, sutures are placed superiorly and two sutures are placed inferiorly. (C) Occasionally, superior vertical divergent sutures are placed along the tear site to help stabilize the repair. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus tears: diagnosis, repair techniques, clinical outcomes, 733-771, Copyright Saunders, 2009.[40]

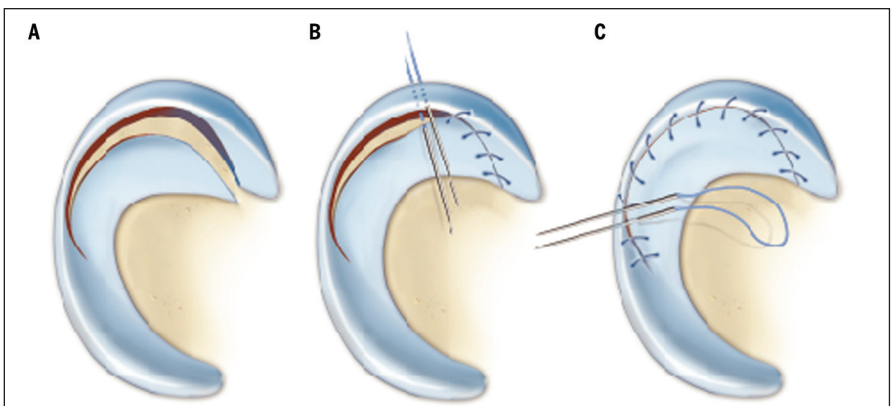

FIGURE 6. Repair technique for flap tears. (A) The tear is identified and reduced. (B) Horizontal tension sutures are placed to anchor the radial component of the tear. (C) The longitudinal component is sutured using the double-stacked suture technique. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus tears: diagnosis, repair techniques, clinical outcomes, 733-771, Copyright Saunders, 2009.[40]

For medial meniscus transplants, a 4-cm skin anteromedial incision is made adjacent to the patellar tendon and a second 3-cm vertical posteromedial incision is made, as previously described.[40] In the central bone bridge technique, the transplant is prepared using either a rectangular or dovetail technique. The meniscus is passed into the joint as described previously and positioned in the medial joint. The meniscus fixation is similar to that of the lateral transplant.

If it is determined that the central bone bridge technique is not acceptable,

TABLE 2 Indications and Contraindications for Meniscus Transplantation

Indications

- Prior meniscectomy
- Patients 50 years of age or younger
- Pain in the meniscectomized tibiofemoral compartment
- No radiographic evidence of advanced joint deterioration, ⩾2 mm of tibiofemoral joint space on 45° weight-bearing posteroanterior radiographs
- No or only minimal bone exposed on tibiofemoral surfaces
- Normal axial alignment

Contraindications

- Advanced knee joint arthrosis with flattening of the femoral condyles, concavity of the tibial plateau, and osteophytes that prevent anatomic seating of the meniscus transplant
- Uncorrected varus or valgus axial malalignment
- Uncorrected knee joint instability, anterior cruciate ligament deficiency
- Knee arthrofibrosis
- Significant muscular atrophy
- Prior joint infection with subsequent arthrosis
- Symptomatic, noteworthy patellofemoral articular cartilage deterioration
- Obesity (body mass index >30 kg/m^2)
- Prophylactic procedure (asymptomatic patients with no articular cartilage damage)

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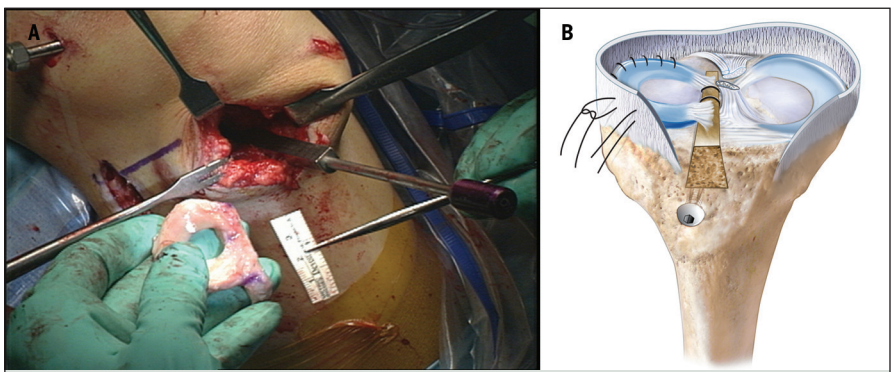

FIGURE 7. (A) A lateral meniscus transplant is ready to be placed into the tibial slot using the central bone bridge technique. Reprinted with permission from Noyes FR, Barber-Westin SD, Rankin M. Meniscal transplantation in symptomatic patients less than fifty years old. *J Bone Joint Surg Am*. 2005;87 suppl 1 pt 2:149-165.[47] (B) A lateral meniscus graft in place and sutured. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus transplantation: diagnosis, operative techniques, clinical outcomes, 772-805, Copyright Saunders, 2009.[41]

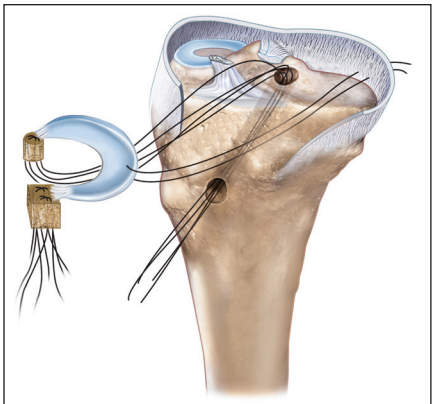

FIGURE 8. Two-tunnel technique for medial meniscus allografts showing insertion of transplant, including the posteromedial suture placed to facilitate meniscus reduction. The anterior and posterior bone attachments of the medial meniscus transplant are fixed into separate tibial tunnels. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus transplantation: diagnosis, operative techniques, clinical outcomes, 772-805, Copyright Saunders, 2009.[41]

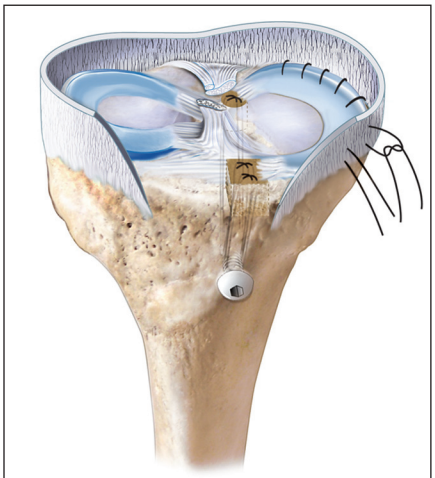

FIGURE 9. Final anterior and posterior tunnel fixation appearance of medial meniscus transplant and vertical divergent sutures. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Meniscus transplantation: diagnosis, operative techniques, clinical outcomes, 772-805, Copyright Saunders, 2009.[41]

separate anterior and posterior tibial bone attachments are prepared for the medial meniscus transplant, which are secured to the normal anatomic attachment sites (**FIGURE 8**). Two sutures are passed retrograde through each bone attachment, with 2 additional locking sutures placed in the meniscus for secure fixation. The anteromedial and posteromedial approaches are performed as already described. A tibial tunnel is drilled over the guide wire. The graft is passed through the anteromedial arthrotomy. A guide wire is passed retrogradely through the tibial tunnel, and the sutures attached to the posterior bone are retrieved. A second suture is placed into the posterior horn and passed inside-out through the posteromedial approach to guide the meniscus.

The posterior meniscus bone attachment sutures are tied over the tibial post to provide tension to the posterior bone attachment. A 12-mm rectangular bone

TABLE 3 Rehabilitation Protocol Summary for Meniscus Repairs and Transplants*

	Postoperative Weeks					Postoperative Months			
	1-2	3-4	5-6	7-8	9-12	4	5	6	7-12
Brace									
Long-leg postoperative	C, A, T	C, A, T	C, T						
Range-of-motion minimum goals									
0° to 90°	X								
0° to 120°		X							
0° to 135°			X						
Weight bearing									
Toe touch: half body weight	P								
Three-quarters to full		P							
Toe touch: one-quarter body weight	C, T, A								
Half to three-quarters body weight		C, T, A	C, A						
Full			T	C, A					
Patellar mobilization	X	X	X						
Stretching									
Hamstring, gastroc-soleus, iliotibial band, quadriceps	X	X	X	X	X	X	X	X	X
Strengthening									
Quadriceps isometrics, straight leg raises, active knee extension	X	X	X	X	X	X	X	X	X
Closed-chain: gait retraining, toe raises, wall sits, minisquats		P	C	X	X	X	X	X	
Knee flexion hamstring curls (90°)			P	C	X	X	X	X	X
Knee extension quadriceps (90°-30°)			X	X	X	X	X	X	X
Hip abduction-adduction, multihip			X	X	X	X	X	X	X
Leg press (70°-10°)			P	P	X	X	X	X	X
Balance/proprioceptive training									
Weight shifting, minitrampoline, BAPS, BBS, plyometrics	P	X	X	X	X	X	X	X	X
Conditioning									
Upper-body ergometer		X	X	X					
Bike (stationary)				X	X	X	X	X	X
Aquatic program					X	X	X	X	X
Swimming (kicking)					P, C	X	X	X	X
Walking					X	X	X	X	X
Stair-climbing machine					P, C	P, C	P, C	P, C	X
Ski machine					P	P	P	C	X
Running									
Straight†						P	P	C	X
Cutting									
Lateral carioca, figure-of-eight†							P	P	X
Full sports†							P	P	X

Abbreviations: A, all-inside meniscus repairs; BAPS, Biomechanical Ankle Platform System; BBS, Biodex Balance System; C, complex inside-out meniscus repairs extending into middle third region; P, peripheral meniscus repairs; T, transplants; X, all meniscus repairs and transplants.
**Modified from Heckmann et al,[22] with permission.*
†Return to running, cutting, and full sports based on multiple criteria. Patients with noteworthy articular cartilage damage are advised to return to light recreational activities only.

attachment is fashioned in the tibia to correspond to the anterior bone attachment of the meniscus graft. The sutures are passed through the bone tunnel, and the anterior horn is seated. Full knee flexion and extension are performed to determine proper graft placement and fit.

The anterior arthrotomy is closed and the suture cannula is inserted into the lateral portal for the meniscal repair. The meniscal repair is performed in an inside-out fashion, with multiple vertical divergent sutures both superiorly and inferiorly (**FIGURE 9**). After final inspection of the graft with knee flexion and extension and tibial rotation, the operative wounds are closed in a routine fashion.

TABLE 4 Postoperative Signs and Symptoms Requiring Prompt Treatment*

Postoperative Sign/Symptom	Treatment Recommendations
Continued pain in the medial or lateral tibiofemoral compartment of the meniscus repair or transplant	Physician examination: assess need for refixation or rerepair
Tibiofemoral compartment clicking or a subjective sensation by the patient of "something being loose" within the tibiofemoral joint	Physician examination: assess need for refixation or rerepair
Failure to meet knee extension and flexion goals	Overpressure program: early gentle manipulation under anesthesia if 0° to 135° not met by 6 wk after surgery
Decreased patellar mobility (indicative of early arthrofibrosis)	Aggressive knee flexion, extension overpressure program, or gentle manipulation under anesthesia to regain full ROM and normal patellar mobility
Decrease in voluntary quadriceps contraction and muscle tone, advancing muscle atrophy	Aggressive quadriceps muscle strengthening program, EMS
Persistent joint effusion, joint inflammation	Aspiration, rule out infection, close physician observation

Abbreviations: EMS, electrical muscle stimulation; ROM, range of motion.
**Modified from Heckmann et al,[22] with permission.*

POSTOPERATIVE REHABILITATION

Clinical Concepts

The postoperative program for meniscus repair and transplantation is shown in **TABLE 3** and has been described elsewhere in detail.[23] Excessive weight bearing is prevented early postoperatively, as high compressive and shear forces can disrupt healing meniscus repair sites (especially radial repairs) and transplants. Variations are built into the protocol according to the type, location, and size of the meniscus repair, and whether concomitant procedures, such as ligament reconstructions, have been performed.

Meniscus repairs located in the periphery (outer one-third region) heal rapidly, whereas complex multiplanar repairs that extend into the central one-third region tend to heal more slowly and require greater caution. In addition, all-inside meniscus repair techniques that use only a few sutures require a delay in achieving full weight bearing and protection to prevent separation at the meniscus repair site. It is imperative that the therapist have knowledge of the type of meniscus repair procedure that was performed to institute the preferred postoperative program. We believe that the multiple vertical divergent suture technique allows for a more progressive rehabilitation program and that the efficacy of early full weight bearing after all-inside suture repairs is not established.

Other modifications to the postoperative exercise program may be required if noteworthy articular cartilage deterioration is found during the operative procedure. This rehabilitation program has been used at our institution in hundreds of meniscus transplant and repair recipients, and the results of clinical investigations[37,38,46,59] demonstrate its safety and effectiveness in restoring normal knee motion, muscle, and gait characteristics.

Patients receive instructions regarding the postoperative protocol before surgery so that they have a thorough understanding of what is expected after surgery. Patients are warned that an early return to strenuous activities, including impact loading, jogging, deep knee flexion, or pivoting, carries a definite risk of a repeat meniscus tear or tear to the transplant. This is particularly true in the first 4 to 6 months after surgery. The supervised rehabilitation program is supplemented with home exercises to be performed daily. The therapist routinely examines the patient in the clinic to implement and progress the appropriate protocol.

Immediate Postoperative Management

Important early postoperative signs for the therapist to monitor after meniscus repair and transplantation include effusion, pain, gait, knee flexion and extension range of motion (ROM), patellar mobility, strength and control of the lower extremity, lower extremity flexibility, and tibiofemoral symptoms indicative of a meniscal tear (**TABLE 4**). Early control of postoperative effusion is essential for pain management and early quadriceps re-education. Compression and cryotherapy are critical during this time. Patients are instructed to maintain lower-limb elevation as frequently as possible during the first week. A portable neuromuscular electric stimulator may be helpful for quadriceps re-education and pain management.[27] This device is used 6 times per day, 15 minutes per session, until the patient displays an excellent voluntary quadriceps contraction.

The patient's initial response to surgery and progression during the first 2 weeks set the tone for the initial phase of rehabilitation. Common postoperative complications include excessive pain or swelling, quadriceps shutdown or loss of voluntary isometric contraction, limitation of ROM, and saphenous nerve irri-

TABLE 5 Range of Motion, Flexibility, and Modality Usage Following Meniscus Repair and Transplantation

Postoperative Time, Frequency	Extension/ Flexion Limits	Patellar Mobilization	Flexibility (5 Reps × 20 s)	Electrical Muscle Stimulation (20 min)	Cryotherapy (20 min)
1 to 2 wk, 3 to 4 times per day, 10-min sessions	0° to 90°	Medial/lateral, superior/inferior	Hamstring, gastroc-soleus	Yes	Yes
3 to 4 wk, 3 to 4 times per day, 10-min sessions	0° to 120°	Medial/lateral, superior/inferior	Hamstring, gastroc-soleus	Yes	Yes
5 to 6 wk, 3 times per day, 10-min sessions	0° to 135°	Medial/lateral, superior/inferior	Hamstring, gastroc-soleus	Yes	Yes
7 to 8 wk, 2 times per day, 10-min sessions	0° to 135°	If required	Hamstring, gastroc-soleus, quadriceps, iliotibial band	No	Yes
9 to 52 wk, 2 times per day, 10-min sessions	Should be normal	None	Hamstring, gastroc-soleus, quadriceps, iliotibial band	No	Yes

Abbreviation: reps, repetitions.
**From Heckmann et al,[22] with permission.*

tation for medial meniscus repairs. It is important to monitor patient complaints of posteromedial or infrapatellar burning, posteromedial tenderness along the distal pes anserine tendons, tenderness of Hunter's canal along the medial thigh, hypersensitivity to light pressure, or hypersensitivity to temperature change. These abnormal symptoms or signs occur in the early stages of complex regional pain syndrome[60] and require immediate treatment.

Brace and Crutch Support

A long-leg postoperative brace is applied immediately after surgery following complex meniscus repairs or transplants. The brace allows from 0° to 90° of motion, but is locked at 0° of extension at night for the first 2 weeks. The brace is used for 6 weeks for complex meniscus repairs and transplants. A brace is not routinely used after repair of a peripheral meniscus tear unless added protection is desired following surgery using an all-inside fixator with only a few sutures. The use of crutches with partial weight bearing is recommended for the time periods shown in **TABLE 3**. Weight bearing is gradually progressed and patients are encouraged to use a normal gait pattern, avoiding a locked knee and using normal flexion motion throughout the gait cycle.

Knee Motion and Flexibility

Passive knee flexion and passive and active/active-assisted knee extension exercises are begun the first day postoperatively for all patients who undergo meniscus repair or transplantation (**TABLE 5**). Active knee flexion is avoided to prevent hamstring strain to the posteromedial joint. Knee motion exercises are performed in the seated position initially from 0° to 90° of flexion. Patients who have had complex or all-inside repairs or meniscus transplantation may be required to limit knee motion to 0° to 90° for the first 2 weeks. Hyperextension is avoided in individuals who have had anterior horn meniscus repairs. Knee motion exercises are accompanied by patellar mobilization (in the superior, inferior, medial, and lateral directions), which is paramount to achieve full knee motion. Flexibility exercises, beginning with hamstring and gastroc-soleus muscle stretches, are begun the first day after surgery.

If 0° to 90° of knee motion are not easily achieved by the end of the first postoperative week, the patient may be at risk of a knee motion complication. Individuals who develop such a limitation are placed into a specific treatment program, which has been previously described in detail.[43] Overpressure exercises and modalities are usually successful in achieving the last few degrees of extension if initiated within the first few weeks after surgery. The goal is to produce a gradual stretching of posterior capsular tissues, but not to induce soft tissue tearing and further injury, as this could lead to an inflammatory response. One effective exercise consists of propping the foot and ankle on a towel or other object to elevate the posterior aspect of the lower extremity off the table, which allows the knee to drop toward full extension. This position is maintained for 10 to 15 minutes and repeated at least 8 times per day. Initially, a 4.5-kg weight, which may be progressed up to 11.4 kg, is applied over the distal thigh to provide overpressure to stretch the posterior aspect of the knee. If these treatment measures are not effective, a dropout (bivalved) cast (**FIGURE 10**) is used to provide continuous extension overpressure. The advantage of this technique is that the patient, having greater control of the process, can apply or remove wedge material as tolerated and bathe. When indicated, the cast is used within the first 4 weeks for cases resistant to the other overpressure extension modalities. Casting is not recommended

FIGURE 10. Dropout cast. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Prevention and treatment of knee arthrofibrosis, 1053-1095, Copyright Saunders, 2009.[43]

in knees with greater than a –12° extension deficit with a hard block to terminal extension.

Flexion exercises are performed in the seated position, using the opposite lower extremity to provide overpressure. Chair rolling, wall sliding, passive quadriceps stretching, and commercial knee motion devices (**FIGURE 11**) are helpful in regaining full knee flexion. The goal of these exercises and modalities is to gradually and passively stretch tissues in a controlled manner, while not inducing pain or the tearing of tissues. Patients who have difficulty achieving 90° by the third to fourth week may require a gentle ranging of the knee under anesthesia (not a forceful manipulation), by which full flexion is typically obtained with only light loads applied. Close supervision and additional exercises may be required in patients who undergo combined procedures to successfully restore normal knee motion.

Balance and Proprioceptive Training

Patients with peripheral meniscus repairs begin balance and proprioception exercises when partial weight bearing has been achieved, which is usually 1 week after surgery. Those with complex meniscus repairs or transplants begin these exercises 3 to 4 weeks after surgery. Crutch support is maintained during these exercises until full weight bearing is achieved.

All patients begin balance training by performing weight shifting from side to side and front to back. Then, walking over cups or cones (**FIGURE 12**) is encouraged to develop symmetry between the surgical and contralateral limbs, hip and knee flexion, quadriceps control during midstance, hip and pelvic control during midstance, and adequate gastrocsoleus control during push-off. Tandem stance balance is also initiated to assist with position sense and balance. Patients perform single-leg balance exercises by pointing the foot straight ahead, flexing the knee to 20° to 30°, extending the arms outward to horizontal, and positioning the torso upright with the shoulders above the hips and the hips above the ankles. This position is held until balance is perturbed. A minitrampoline makes this exercise more challenging after it has been mastered on a hard surface.

FIGURE 11. Knee flexion overpressure device. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Prevention and treatment of knee arthrofibrosis, 1053-1095, Copyright Saunders, 2009.[43]

Many devices are available to assist all patients with balance and gait retraining, including styrofoam half rolls and whole rolls, and the Biomechanical Ankle Platform System (Dynatronics Corporation, Salt Lake City, UT). Patients walk (unassisted) on styrofoam half rolls to develop a center of balance, quadriceps control in midstance, and postural positioning. More sophisticated commercial devices are also available that provide visual feedback to assist with a variety of balance activities, including Biodex's Balance System (Biodex Medical Systems, Shirley, NY) and Neurocom's Balance System (NeuroCom, Clackamas, OR).

FIGURE 12. Cup walking is used early after surgery to develop symmetry between limbs, hip and knee flexion, quadriceps control during midstance, hip and pelvic control during midstance, and adequate gastrocnemius-soleus control during pushoff. This exercise also facilitates quadriceps control to prevent knee hyperextension from occurring during gait. This figure was published in *Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes*, Noyes FR, Barber-Westin SD, Prevention and treatment of knee arthrofibrosis, 1053-1095, Copyright Saunders, 2009.[43]

Strengthening

Quadriceps isometrics, straight leg raises, and active-assisted knee extension from 90° to 0° of knee flexion are begun the first day after surgery (**TABLE 6**). The only exception is for patients with anterior horn meniscus repairs, in whom active-assisted knee extension is limited from 90° to 30°. Straight leg raises are performed in the flexion plane only until the patient demonstrates a sufficient quadriceps contraction to eliminate any extensor lag. Then, straight leg raises in

TABLE 6 Muscle-Strengthening Exercises Following Meniscus Repair and Transplantation*

PO Time, Frequency	Quadriceps Isometrics (Active, 90°-0°)	Straight Leg Raises	Knee Extension	Toe Raises	Wall Sits (to Fatigue)
1 to 2 wk, 3 times per d, 15 min	1 set of 10 reps every h	Flexion, 3 sets of 10 reps	Active-assisted, 90° to 0° all but anterior horn repairs, 90° to 30°, 3 sets of 10 reps		
3 to 4 wk, 2 to 3 times per d, 20 min	Multiangle (0°, 60°), 1 set of 10 reps each	Flexion, extension, adduction, 3 sets of 10 reps	Active-assisted, 90° to 0° all but anterior horn repairs, 90° to 30°, 3 sets of 10 reps	Meniscus repairs only, 3 sets of 20 reps	Meniscus repairs only, 3 sets
5 to 6 wk, 2 times per d, 20 min	Multiangle (30°, 60°, 90°), 2 sets of 10 reps	Add ankle weight, ≤10% of body weight, 3 sets of 10 reps	Active, 90° to 30°, 3 sets of 10 reps	All; meniscus repairs: add heel raises, 3 sets of 10 reps	Transplants start, 3 sets
7 to 8 wk, 2 times per d, 20 min		Add abduction, 3 sets of 10 reps Add rubber tubing, 3 sets of 30 reps	Active, 90° to 30°, 3 sets of 10 reps	Transplants: add heel raises, 3 sets of 10 reps	3 sets
9 to 12 wk, 2 times per d, 20 min		3 sets of 10 reps Rubber tubing, 3 sets of 30 reps	Active, 90° to 30°, 3 sets of 10 reps		3 sets
13 to 26 wk, 2 times per d, 20 min		Rubber tubing, high-speed, 3 sets of 30 reps	Active, 90° to 30° with resistance, 3 sets of 10 reps		
27 to 52 wk, 1 time per d, 20 to 30 min		Rubber tubing, high speed, 3 sets of 30 reps	Active, 90° to 30° with resistance 3 sets of 10 reps		

Table continued on page 285.

the other 3 planes (abduction, adduction, and extension) are added.

Closed-kinetic-chain weight-bearing exercises begin during postoperative weeks 3 to 4. The program incorporates toe raises, wall sits, and minisquats when patients are 50% weight bearing. These activities are limited from 0° to 60° of flexion to protect the posterior horn of the meniscus.

Open-kinetic-chain non–weight-bearing exercises begin 5 to 6 weeks after surgery. Knee extension progressive resistive exercises are initiated from 90° to 30° to protect the patellofemoral joint.[19] By keeping the quadriceps exercises in this protected ROM, minimal forces will be placed along peripheral and midsubstance repair sites.

Hamstring curls from 0° to 90° are initiated in patients who had peripheral meniscus repairs at the same time as the knee extension progressive resistive exercises. Care should be taken to avoid hyperextension, which places tension on the posterior capsule. This exercise is delayed until at least 7 to 8 weeks after a complex meniscus repair, and until 9 to 12 weeks after meniscus transplantation. Isolated resisted hamstring curls are limited in complex medial meniscus repairs and medial meniscus transplants, due to the medial hamstring insertion along the posteromedial joint capsule. This exercise is also delayed in lateral meniscus transplant patients, as a greater pull of the lateral portion of the hamstrings compared to the medial portion may increase tibial rotation. This limitation is designed to lessen potential traction forces being imposed onto the repair and transplant sites. Patients are monitored as they perform this exercise, to ensure that a neutral pull and no tibial rotation occur.

Exercise on the leg press machine is initiated as early as 4 weeks after peripheral meniscus repairs. The ROM is limited to 60° to 10° to protect against excess loading of the posterior horn of the meniscus, which occurs at knee flexion angles greater than 60°, and high forces on the patellofemoral joint. This limitation of motion is also advantageous because it requires increased control from the quadriceps musculature. For complex meniscus repairs, exercise on the leg press is delayed until week 6 to allow for sufficient healing of the repair. This exercise is initiated between weeks 9 and 12 for meniscus transplants.

Conditioning

A cardiovascular program may be initiated as early as 3 to 4 weeks after surgery if the patient has access to an upper-body ergometer (**TABLE 7**). Stationary bicycling begins 7 to 8 weeks after surgery. The seat height is adjusted to its highest level based on the patient's body size, and a

TABLE 6 Muscle-Strengthening Exercises Following Meniscus Repair and Transplantation* (continued)

PO Time, Frequency	Minisquats	Lateral Step-ups (5- to 10-cm Block)	Hamstring Curls (0°-90°)	Multihip Flexion, Extension, Abduction, Adduction	Leg Press (70°-10°)
1 to 2 wk, 3 times per d, 15 min					
3 to 4 wk, 2 to 3 times per d, 20 min	Meniscus repairs only, 3 sets				
5 to 6 wk, 2 times per d, 20 min	Transplants start, 3 sets		Peripheral repairs only, active, 3 sets of 10 reps	3 sets of 10 reps	Peripheral meniscus repairs only, 3 sets of 10 reps
7 to 8 wk, 2 times per d, 20 min	3 sets	3 sets of 10 reps	All meniscus repairs only, active, 3 sets of 10 reps	3 sets of 10 reps	Peripheral meniscus repairs only, 3 sets of 10 reps
9 to 12 wk, 2 times per d, 20 min	Add rubber tubing, 0° to 40°, 3 sets of 20 reps	3 sets of 10 reps	Transplants. start active, 3 sets of 10 reps	3 sets of 10 reps	Transplants, start 3 sets of 10 reps
13 to 26 wk, 2 times per d, 20 min	3 sets of 20 reps		Add resistance, 3 sets of 10 reps	3 sets of 10 reps	3 sets of 10 reps
27 to 52 wk, 1 time per d, 20 to 30 min	3 sets of 20 reps		With resistance, 3 sets of 10 reps	3 sets of 10 reps	3 sets of 10 reps

Abbreviations: PO, postoperative; reps, repetitions.
**Exercises done by recipients of either meniscus repair or transplantation unless otherwise indicated. From Heckmann et al,[22] with permission.*

low resistance level is used. A recumbent bicycle may be substituted for patients who have damage to the patellofemoral joint articular cartilage or anterior knee pain. Water walking may be implemented during this time frame. To protect the healing meniscus, swimming with straight-leg kicking and dry-land walking programs are initiated between 9 and 12 weeks after surgery. Protection against high stresses to the patellofemoral joint is required in patients with symptoms or articular cartilage damage. The cardiovascular program should be done at least 3 times a week for 20 to 30 minutes, and the exercise performed to at least 60% to 85% of maximal heart rate.

Running, Plyometric Training, and Return-to-Sport Activities

A running program is begun at approximately 20 weeks postoperatively in patients who have had peripheral meniscus repairs and who have an average peak torque deficit of no more than 30% for the quadriceps and hamstrings with isometric testing performed on an isokinetic dynamometer. This program is delayed until approximately 30 weeks postoperatively in patients who had complex meniscus repairs, and until at least 1 year postoperatively in patients who had a meniscus transplant. Patients begin with a walk-run combination program, using running distances of between 18 and 91 m. Initially, patients run at 25% to 50% of their normal speed. Once they are able to run straight ahead at full speed, lateral and crossover maneuvers are added. Short distances, such as 18 m, are used to work on speed and agility. Side-to-side running over cups, figures-of-eight, and carioca running drills may be used to facilitate agility and proprioception.

Progressive plyometric training is initiated in select patients upon successful completion of the running program, as described in detail elsewhere.[23] These activities are typically incorporated after 6 months postoperatively in patients who have had a large peripheral tear or complex repair. In patients who had a radial meniscus repair, this program may be delayed until 9 months postoperatively, due to the disruption that occurred in the hoop stresses of the meniscus.

The clearance for return to athletics is based on successful completion of the running and functional training programs. Muscle and functional testing should be within normal limits, and a trial of function is encouraged, during which the patient is monitored for symptoms. The majority of patients who undergo meniscal transplantation have noteworthy articular cartilage deterioration and are not candidates for strenuous plyometric training or heavy-impact sports activities.

CLINICAL OUTCOME STUDIES

Meniscus Repair

We have summarized the results of meniscal repair from a variety of studies published over the last 10 years.[40] Most investigations have focused on vertical meniscus suture repair techniques; few have reported on the outcome of horizontal suture repair or all-inside fixators. Failure rates of suture repairs vary greatly, as do correlations with side of meniscus tear, concurrent ACL reconstruction, location of meniscus tear, age, and gender. Investigations of newer all-inside suture systems have reported acceptable failure rates

TABLE 7 Aerobic-Conditioning Exercises Following Meniscus Repair and Transplantation*

PO Time, Frequency	Upper-Body Ergometer	Bicycle (Stationary)	Water Walking	Swimming	Walking
3 to 4 wk, 1 to 2 times per d	10 min				
5 to 6 wk, 2 times per d	10 min				
7 to 8 wk, 1 to 2 times per d	15 min	15 min			
9 to 12 wk, once per d (select 1 activity per session)		15 min	15 min	15 min	15 min
13 to 26 wk, 3 times per wk, (select 1 activity per session)		20 min	20 min	20 min	20 min
20 wk, 3 times per wk (peripheral meniscus repairs only)†					
27 wk and beyond, 3 times per wk (select 1 activity per session)		20 to 30 min	20 to 30 min	20 to 30 min	20 to 30 min
30 wk and beyond					
12 mo and beyond					

Table continued on page 287.

between 9% and 13%.[8,21,25,28,29,51] However, long-term, clinical follow-up reports are required of these systems. Most authors use an average of 2 sutures, and there is concern regarding the expected inferior fixation strength of these techniques compared to the multiple vertical divergent suturing procedure.

We have published a series of studies[11,37-39,59] that provide the outcomes of 198 complex meniscus repairs that extended into the central-third avascular region in 177 patients aged 9 to 53 years. These repairs were performed with the inside-out vertical divergent suture technique described previously. Patients underwent either a clinical examination a minimum of 2 years postoperatively or follow-up arthroscopy. ACL ruptures were present in 128 of the patients, of whom 126 underwent ACL reconstruction. We found that, for all 198 repairs, the reoperation rate for tibiofemoral compartment pain symptoms was 20%. Statistically significant differences were found in the rates of meniscus repair healing for 3 factors: tibiofemoral compartment of the meniscus repair (higher healing rate in lateral meniscus repairs compared to medial meniscus repairs), time from repair to follow-up arthroscopy (higher healing rate in patients evaluated at 12 months or less compared to those evaluated at more than 12 months postoperatively), and the presence of tibiofemoral symptoms (higher healing rate in asymptomatic patients compared to symptomatic patients).

We assessed the results of meniscus repairs in a subgroup of patients 40 years of age and older.[38] At follow-up, 26 repairs (87%) had no tibiofemoral joint symptoms and had not required further surgery, demonstrating that repair of complex tears in older adults is feasible and that the majority are asymptomatic for tibiofemoral joint symptoms an average of 3 years postoperatively.

Another study was conducted in a subgroup of 58 patients under the age of 20.[37] Skeletal maturity had been reached in 54 knees (88%). ACL reconstruction was done either with or staged after the meniscus repair in 47 knees (81%). At follow-up, 53 meniscal repairs (75%) had no tibiofemoral symptoms and had not failed on follow-up arthroscopy.

A long-term study was completed on a subgroup of 29 meniscus repairs done in patients under the age of 20.[48] The mean follow-up was 16.8 years (range, 10.1-21.9 years). Eighteen repairs were evaluated by follow-up arthroscopy, 19 by clinical evaluation, 17 by MRI, and 22 by weight-bearing PA radiographs. A 3-T MRI scanner with cartilage-sensitive pulse sequences and T2 mapping was used. The results showed a clinical success rate (asymptomatic patients) of 79% and a biologic success rate of 62%. Using strict criteria, 18 (62%) of the meniscus repairs had normal or nearly normal characteristics. Six repairs (21%) required arthroscopic resection, 2 had loss of joint space on radiographs, and 3 that were asymptomatic failed according to MRI criteria. There was no significant difference in the mean T2 scores in the menisci that had not failed between the involved and contralateral tibiofemoral compartments. We concluded that the ability to provide long-term meniscus function with an inside-out vertical divergent suture technique appears to warrant this procedure over resection, which has a well-documented poor outcome.[3,34,54,57,58,61]

In the future, tissue engineering may provide increased success rates of meniscus repair, especially for tears that extend into the avascular region.[1,10,13,15,65] Cell-based therapy using meniscal fibrochondrocytes, articular chondrocytes, or mesenchymal stem cells seeded onto scaffolds offers promise,[56,64] as does the introduction of growth factors into repair sites.

Meniscus Transplantation

Since 1984, over 30 clinical investigations have reported results of meniscus transplant surgery, and the results of these reports have been summarized elsewhere.[41] Differences in tissue processing, secondary sterilization, preservation, operative technique, and rating schemes make comparisons between studies difficult; however, others have performed lengthy reviews of these investigations.[14,31,55] Although results are mixed, long-term studies have shown enough benefits to

TABLE 7 Aerobic-Conditioning Exercises Following Meniscus Repair and Transplantation* (continued)

PO Time, Frequency	Stair Climbing Machine (Low Resistance, Low Stroke)	Ski Machine (Short Stride, Level, Low Resistance)	Running (Straight)	Cutting	Functional Training
3 to 4 wk, 1 to 2 times per d					
5 to 6 wk, 2 times per d					
7 to 8 wk, 1 to 2 times per d					
9 to 12 wk, once per d (select 1 activity per session)	Meniscus repairs only, 15 min	Meniscus repairs only, 15 min			
13 to 26 wk, 3 times per wk (select 1 activity per session)	Meniscus repairs only, 20 min	Meniscus repairs only, 20 min			
20 wk, 3 times per wk (peripheral meniscus repairs only)†			Jog one-quarter mile, walk one-eighth mile, backward run 20 yd	Lateral, carioca, figure-of-eight, 20 yd	Plyometrics: box hops, level, double-leg, 15 s, 4 to 6 sets Sport-specific drills, 4 to 6 sets
27 wk and beyond, 3 times per wk (select 1 activity per session)	20 to 30 min	20 to 30 min			
30 wk and beyond			Complex meniscus repairs, start 30 wk postoperatively Advance program as needed	Complex meniscus repairs, start beyond 35 wk postoperatively Advance program as needed	Complex meniscus repairs, start beyond 35 wk postoperatively Advance program as needed
12 mo and beyond			Transplants start, with precautions		

Abbreviation: PO, postoperative.
**Exercises done by recipients of either meniscus repair or transplantation unless otherwise indicated.*
†Begin running program when no more than 30% deficit is present on isokinetic testing; begin cutting program when no more than 20% deficit is present on isokinetic testing.

justify the procedure in appropriately indicated patients.[68,69,72,77]

To date, 2 survival-analysis investigations of meniscus transplantation have been published. van Arkel and de Boer[68] followed 63 consecutive cryopreserved meniscal transplants 4 to 126 months after surgery. Persistent pain or mechanical damage (detached or torn transplant) determined transplant failure. The cumulative 10-year survival rates of lateral, medial, and combined transplants in the same knee were 76%, 50%, and 67%, respectively. Verdonk et al[72] followed 100 fresh meniscus transplants a mean of 7.2 years postoperatively. End points for failure were moderate or severe pain, occasional or persistent pain, or poor knee function. The cumulative survival rates at 10 years were 74.2% for medial transplants and 69.8% for lateral transplants. Medial meniscus transplants done concurrently with high tibial osteotomy had a cumulative survival rate of 83.3%.

We previously described the results of 40 consecutive cryopreserved and 96 fresh-frozen irradiated medial and lateral meniscus transplants.[42,45,46,53] A 100% follow-up was obtained in these prospective studies. The cryopreserved transplants were followed a mean of 40 months (range, 24-69 months) postoperatively and the irradiated transplants a mean of 44 months postoperatively (range, 22-111 months). In the cryopreserved transplants, 17 (42.5%) had normal characteristics, 12 (30%) had altered characteristics, and 11 (27.5%) failed, according to strict criteria from follow-up arthroscopy, MRI, and patient symptoms. There was a correlation between the arthritis rating on MRI and the transplant characteristics ($P = .01$). Before surgery, 27 patients (77%) had moderate to severe pain with daily activities; but at follow-up, only 2 patients (6%) had pain with daily activities ($P<.0001$).

The results of the irradiated transplants included a failure rate of 6% (1 of 18) in knees with normal or only mild arthritis on MRI, 45% (14 of 31) in knees with moderate arthritis, and 80% (12 of 15) in knees with advanced arthritis. The relationship between the meniscus

transplant failure rate and increasing severity of joint arthritis was significant ($P<.001$). The role of low-dose irradiation (2.0-2.5 Mrad) in terms of increasing the failure rate is not scientifically known. The increase in failure rate was due, we believed, to many factors that were indicators of a disorderly remodeling process, including minimal cellular repopulation of the central core of the transplant, a disorganized collagen orientation and predominant fibrocyte cellular structure found in several of the failed specimens, and a possible increase in water content and decrease in proteoglycan concentration.[24] Both of our studies showed that patients with advanced arthritis, and alterations in joint geometry (major tibial concavity, femoral condyle flattening) with exposed bone surfaces over the majority of the tibiofemoral compartment are not candidates for meniscus transplantation.

SUMMARY

The preservation of meniscal tissue in active individuals and the poor long-term results of meniscectomy provide overwhelming reasons for the surgeon to make every attempt to repair meniscus tears, including those that extend into the central third avascular region. The most reliable technique uses vertical divergent sutures placed every 4 mm along the length of the tear. Published success rates are greater than 90% for tears located in the periphery and 60% to 80% for those located in the central region. Patients who have undergone meniscectomy may receive improvements in knee function and pain with meniscus transplants. However, the long-term outcomes of this procedure remain unknown. These transplants appear to undergo prolonged remodeling that results in alterations in collagen fiber architecture required for load sharing and survival. The surgeon should advise patients considering this operation that it is not curative in the long term and that additional surgery will most likely be required. Postoperative rehabilitation for both operations includes immediate knee motion, patellar mobilization, and quadriceps strengthening exercises that do not appear to be harmful. Precautions are required in limiting high-loading activities, deep knee flexion, and full squatting for a minimum of 4 to 6 months. ◉

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