MENISCUS TRANSPLANTATION: BONE BRIDGE IN SLOT TECHNIQUE

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The desired outcome of meniscal transplantation is to resolve pain and restore biomechanical function in the symptomatic postmeniscectomy patient. The evolution of the technique has progressed with the premise that the meniscus transplant must participate in load sharing. Biomechanical basic science testing has shown that to participate in force transfer, the meniscus must be anchored anatomically with bony fixation. The goals of the bone bridge in slot technique are to adhere to biomechanical principles on bony fixation, while improving procedure ease and reproducibility.

Key Words: meniscal transplantation, meniscal allograft, meniscectomy, meniscus

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The goal of meniscal allograft transplantation is to restore normal knee anatomy and biomechanics in select symptomatic individuals following meniscectomy. Intermediate-term reports indicate that excellent pain relief and improved function can be achieved when there is rigid adherence to the appropriate indications. Long-term outcome studies of postmeniscectomy patients demonstrate a progressive increase in ipsilateral compartment chondrosis. The degree of degenerative changes is proportional to the amount of meniscus removed, with more predictable progression following lateral meniscectomy. Anatomic and functional restoration of the meniscus has the potential to resolve pain and to improve the natural history of the meniscus-deficient knee.

Howell and associates compared different methods of fixation, and more recently, identified the detrimental effects of subtle malposition of the position of the posterior horn attachment site. They demonstrated that soft tissue fixation alone does not reestablish contact area or normal stress distribution. These studies emphasized the importance of anatomic placement with bony fixation. A bone bridge technique for meniscus allograft transplantation has been used for several years. Potential advantages include (1) maintaining the proper relationship between the anterior and posterior horn attachment sites, (2) decreasing positional error, and (3) firm anatomic attachments allowing the meniscus to "capture the femoral condyle," potentially restoring meniscus function and normalizing tibiofemoral contact pressures.

The principal goals of the technique presented in this article are to reliably, reproducibly, and efficiently restore meniscus function through an arthroscopically assisted technique. This technique is based on the ability to create a uniform slot that parallels the posterior slope of the tibia and is in line with the meniscal horn insertion sites. A slightly undersized meniscus bone bridge allows easy insertion and the femoral condyle to anatomically capture the meniscus prior to rigid biologic fixation of the bone bridge in the slot with an interference bone screw.

INDICATIONS

Ideally, allograft meniscus transplantation is indicated in symptomatic meniscectomized patients with persistent pain in the involved compartment with intact articular cartilage (ie, grade II or less), normal alignment, and a stable joint. While there is no chronologic age limit, patients who are beyond 50 to 55 years of age have usually developed a degree of arthritis that contraindicates them for the procedure. Ligamentous instability and localized chondral defects should be treated concomitantly or staged through ligament reconstruction or cartilage restoration, respectively. Realignment procedures are performed, even when only a few degrees of malalignment toward the involved compartment exists compared to the contralateral limb. Significant articular disease (ie, extensive grade III or IV) and radiographic femoral condyle flattening or marked osteophyte formation are generally associated with inferior results and are considered the most common contraindications.

SURGICAL TECHNIQUE

General

A well-padded leg holder with the leg hanging free in the flexed position allows unimpeded knee flexion and circumferential access to the medial, lateral, and posterior aspects of the knee to facilitate meniscus repair. Tourniquet use is surgeon-dependent. Diagnostic arthroscopy through routine arthroscopic portals is performed to identify all pathology, including that which might contraindicate a patient for the procedure or require concomitant manage-
Advanced chondral disease will otherwise contraindicate the procedure if not addressed through cartilage restoration techniques. Any remaining meniscus remnant is trimmed to within 1 to 2 mm of the capsule in an effort to create a healthy bleeding bed for the transplant (Fig 1).

**Allograft Preparation**

**Bone Bridge Width.** Because the slot which accepts the meniscus is uniform in shape each time, the surgeon or assistant can prepare the allograft before or simultaneously with host tibial preparation. Following complete thawing of the allograft, extraneous soft tissue and capsule are debrided. The meniscal horn insertion sites dictate the location of the medial and lateral bone block cuts. Rotating the meniscus back and forth in a bucket handle fashion will differentiate the true horn attachment site from the accessory tissues, which should be released. The typical horn insertion sites are approximately 5 mm in width, which allows easy incorporation into a 7-mm width bone bridge. Note that the anterior horn of the medial meniscus is variable in size and may range to as wide as 8 to 10 mm, which may require modification of the bone bridge at the anterior most extent to incorporate the entire anterior horn insertion site. The recipient slot is similarly enlarged along its most anterior extent to accommodate this modification to the bone bridge.

**Meniscus Final Preparation.** A line placed 10 mm below each horn insertion site is drawn as a guide to meniscus depth. Note that the bone in the central region of the spine is obviously deeper. This spine area is trimmed to improve visualization during insertion and to avoid impingement on the femoral condyle. The anteroposterior dimensions of the block will be determined by the horn attachments. Trimming the bone obliquely at the posterior margin of the posterior horn insertion site assures that the meniscus will be positioned sufficiently posterior in the recipient tibial slot. The bone bridge of the meniscus is sized using the bone bridge sizing guide to assure that it will fit smoothly in the recipient slot. The bone bridge is forcefully irrigated to decrease residual donor blood products and, thus, antigenicity. A no. 0 polydioxanone suture (PDS) traction suture is placed at the junction of the posterior and middle third of the meniscus soft tissue. The construct is placed in normal saline with antibiotics in a safe location on the back table (Fig 2).

**Host Tibial Slot Preparation**

**Accessory Portal** An anterior transpatellar tendon accessory portal is established exactly in line with the anatomic centers of the anterior and posterior horn insertion sites, identified by using a spinal needle percutaneously positioned over the center of both horn footprints (Fig 3). It is important to recognize that the orientation of this line between the anterior and posterior horns is oblique and thus not necessarily in the exact anteroposterior plane of the tibia. A limited debridement of the ipsilateral tibial spine and adjacent condylar margin is performed to optimize visualization. During the final stages of slot preparation, this portal is lengthened in line with the patellar tendon from the level of the inferior pole of the patella to about 2 cm below the articular surface.
Superficial Reference Slot. A superficial reference slot is established in line with the anterior and posterior horns. This line is created with an electrothermal or mechanical device, which is also used to debride residual soft tissue. A 4-mm arthroscopic burr is placed through the accessory portal to create a 4-mm deep slot beginning at the anterior margin of the tibia and extending posteriorly, preserving 2 to 3 mm of the posterior tibia cortex. It may be necessary to slightly enlarge the reference slot (from medial to lateral) to accommodate the shank of the burr as the cutting proceeds more posteriorly in an effort to create a smooth, flat cancellous floor that is parallel to the tibial plateau (Fig 4).

Drill Guide Placement. The accessory portal is enlarged as previously described. The 4-mm diameter depth gauge arm from the drill guide is placed through the anterior accessory portal and set into the superficial reference slot. The arm is used to confirm the uniformity and depth of the reference slot from anterior to posterior, as the hooked tip engages the residual posterior tibial cortex.

Outside the joint, the drill guide is advanced over the depth gauge arm and positioned directly onto the anterior face of the tibial plateau (while maintaining the depth gauge arm in the reference slot and the arm tip over the posterior tibial cortex). During this phase, the knee is typically "dry," while simultaneously using direct and arthroscopic visualization to verify depth gauge place-
ment. The guide pin is clamped to the laser line in advance, as this corresponds to the depth of the posterior tibial cortex to prevent inadvertent penetration during drilling (Fig 5). The guide pin is fully advanced through the drill guide to the posterior wall. The guide body and depth gauge arm are removed, leaving the guide pin parallel to the tibial slope. It is now 4 mm distal to the superficial reference slot, for a total of 8 mm distal to the initial level of the chondral surface.

An indirect depth gauge is used to determine the length required for reaming, using the 8-mm cannulated reamer. In addition, the reamer is carefully advanced using tactile feedback with caution to prevent inadvertent penetration of the posterior tibial cortex. This blind tunnel is centered 8 mm distal to the chondral surface, and following reaming, the floor of the tunnel will be 12 mm distal to the chondral surface (Fig 6).

Slot Preparation. The blind tunnel and overlying superficial reference slot are made confluent using the bullet tipped box chisel. The retracting bullet tip of the box chisel engages the blind tunnel, maintaining the chisel parallel to the tunnel (Fig 7). During insertion of the chisel, it is important to be sure the blades are visible arthroscopically or directly, as they penetrate just above the chondral surface. This technique prevents the blade from “snowplowing” beneath the chondral surface, potentially leading to an uncontrolled fracture of the subchondral plate and attached chondral surface. On the medial side, this fracture could compromise the anterior cruciate ligament (ACL) tibial attachment site. Residual debris along the slot is removed with a pituitary rongeur and curette. Retained posterior debris must be removed until the posterior cortex is palpable and clearly visualized.

To convert the U-shaped opening to a rectangle, the 7-mm sizing rasp is gently inserted (facilitated by light tapping with a mallet) until a smooth back-and-forth motion is achieved by hand alone. Next, the slot is enlarged with the 8-mm sizing rasp. The top of the rasp should sit flush with the subchondral bone, equivalent to the depth

Fig 6. (A) An 8-mm cannulated reamer used to create recipient socket for box cutter. (B) Clinical example of cannulated reamer.

Fig 7. (A) Box chisel is impacted into place to transform cylindrical socket to a rectangular socket. (B) Clinical example of box chisel nose seated in preparation for impaction.
nula. Using the contralateral portal, it passes through the meniscal remnant at the junction of the posterior and middle third of the host meniscus rim, so as to exit the accessory posteromedial or posterolateral incision. The loop end of the Nitinol pin is retrieved through the accessory portal. The no. 0 PDS traction sutures from the donor meniscus are passed through the loop, and the Nitinol pin is withdrawn from the posterior accessory incision. The bone bridge is manually introduced into the slot under direct visualization, with gentle traction placed on the exiting traction suture. Manually advancing the bridge through the accessory incision with varus (lateral transplant) or valgus (medial transplant) stress in variable degrees of flexion facilitates atraumatic advancement of the bone bridge. Once the bone bridge is seated posteriorly, the soft tissue portion of the meniscus is fully reduced by gently pulling the traction suture and further facilitated by the blunt end of a nerve hook. Once reduced, a correctly sized meniscus will be captured by the femoral condyle during repeated flexion and extension of the knee. This aids the final selection of the AP position of the bone bridge.

Fig 8. (A) An 8-mm sizing rasp is inserted to contour the U-shaped opening to a rectangular opening. (B) Clinical example of sizing rasp introduced into opening. (C) Arthroscopic appearance of fully seated rasp.

of the prepared bone bridge (10 mm), as the articular cartilage varies to approximately a 2 mm depth in this region (Fig 8).

Meniscus Insertion. A flexible Nitinol suture-passing pin is passed through a properly positioned zone-specific can-

Fig 9. (A) Interference screw made of cortical bone is positioned against meniscus bridge at base of the bone block to compress it within the recipient slot. (B) Arthroscopic view of screw as it parallels bone bridge.
bridge. The meniscus soft tissues should move smoothly without subluxation. The most common malposition is for the transplant to be too far anterior.

A blunt elevator is used to hold the meniscus bone bridge in its desired position. An interference screw guide-wire is positioned adjacent to the central aspect of the bone bridge (i.e., side adjacent to cruciate ligament tibial attachment). Tap is used to create threads between the bridge and central wall of the slot. While securely maintaining the position of the bone bridge with the blunt elevator, a 25-mm cortical bone screw is fully inserted, achieving interference fit fixation (Fig 9). The soft tissue portion of the meniscus is then sutured using standard inside-out meniscal repair techniques with vertical mattress sutures on both sides of the meniscus. These are tied directly over the capsule with the knee in extension through a postero-lateral or posteromedial accessory incision. The stability of the soft and bony portions of the transplant is assessed with gentle probing (Fig 10).

POSTOPERATIVE MANAGEMENT

Postoperative management is similar to other meniscal transplant techniques that incorporate bone fixation. Surgeons and patients must respect the biology required for the revascularization and cellular ingrowth that occurs during the postoperative healing phase in an effort to prevent premature overload of the incorporating graft. It is anticipated that an anatomically placed graft with a stable patient-graft interface will function as a 3-dimen-sional construct, restoring the stabilizing and load-sharing protective functions of the native meniscus.

Most surgeons allow range of motion from 0° to 90° with protected weight bearing in a hinged knee immobilizer during the initial 4 to 6 weeks. Thompson et al found that the meniscus shows little movement from 0° to 60° of flexion. As flexion is increased, the meniscus translates posteriorly, resulting in displacement from the capsule and stress upon a posterior repair. With clinical confirmation of this finding, limiting flexion to 90°, especially during weight bearing, seems appropriate. Weight bearing is allowed, but it is commonly restricted due to concerns of graft weakening during revascularization in the early postoperative state. Early phase rehabilitation is otherwise similar to ACL protocols. Achieving full extension is an early goal, and isometric exercises are encouraged to limit muscle atrophy. Closed chain kinetic exercises are begun with weight bearing, but forced flexion and pivoting activities should be avoided. It is generally agreed that patients should have near normal strength and proprioception before strenuous activities and sports are allowed, but opinions vary significantly with respect to that time frame, which ranges between 4 and 12 months. Questions remain regarding whether the intent of the procedure is to return patients to high-impact activities or pain-free activities of daily living (ADLs). Most surgeons follow a program that allows running at 4 to 6 months and full activity at 6 to 9 months.

RESULTS

Collectively, the authors have performed over 150 meniscal transplants to date, with the most recent series of 33 patients being implanted with the bone bridge in slot technique. On average, operative times are generally about 1 hour less than other bone bridge techniques. Radiographic bridge healing is typically seen by 12 weeks (Fig 11). To date, 10 females and 23 males with an average age of 38.5 years (range, 17-57) have been transplanted. This group includes 20 medial and 10 lateral transplants. There were no infections, deep venous thromboses, or complications related to meniscus or screw displacement. There were 4 rears requiring surgery and 1 incomplete healing rim demonstrated by second-look arthroscopy. The incomplete healing rim healed clinically after repair. Of the 4 rears, 3 were traumatic and 1 occurred with a fall that also tore the ACL graft. Treatment of these 4 patients consisted of arthroscopic removal of the soft tissue portion of the transplant, followed by observation in 3 patients and retransplantation in 1 patient who clinically remains asymptomatic after retransplantation. Four patients developed incomplete flexion because of adhesions, 3 of which responded favorably to arthroscopic debridement. The fourth is scheduled for arthroscopy. No instances of
patella infra developed. Twenty-nine of 33 patients felt that the pain relief and functional improvement afforded by the procedure would encourage them to undergo the surgery again.

**SUMMARY**

It is evident that meniscal allograft transplantation offers a viable option to treat the symptomatic meniscus-deficient patient who has no more than grade II or early grade III chondrosis, providing other rigid inclusion criteria are met. Clinical results demonstrate effectiveness in alleviating pain and swelling and in improving knee function. Results are poor in patients with advanced arthrosis, and this remains the primary contraindication to this procedure. The procedure is technically challenging, but the authors believe that the meniscus bridge in slot technique will offer a predictable and reproducible solution to this demanding procedure. Further study will clarify the long-term benefit of meniscal allografts, but in the intermediate term, the results remain particularly encouraging.

**REFERENCES**