ARTHROSCOPICALLY ASSISTED TECHNIQUE FOR PREVENTING ROOF IMPINGEMENT OF AN ANTERIOR CRUCIATE LIGAMENT GRAFT ILLUSTRATED BY THE USE OF AN AUTOGENOUS DOUBLE-LOOPED SEMITENDINOSUS AND GRATILIS GRAFT

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Roof impingement of the anterior cruciate ligament (ACL) graft cannot be seen in the fully extended knee, but roof (notch) impingement can be detected if an impingement rod will not pass through the tibial tunnel into the notch with the knee maximally extended. When we sense impingement by this method, we know that a correction, ie, prevention, must be made so that the ACL graft will not be reruptured, the knee will regain full extension, and the patient can return to activities of choice. Roof impingement occurs when the tibial tunnel is anterior to the slope of the intercondylar roof in the maximally extended knee. The tibial tunnel location must be customized to correct for individual variations in knee hyperextension and in the slope of the intercondylar roof. Unimpinged grafts lie in tibial tunnels that are posterior to the intercondylar roof in the extended knee. The graft must be placed without roof impingement to avoid graft stretch-out and flexion contractures. The arthroscopically assisted technique using the double-looped semitendinosus and gracilis (hamstrings) tendons, a custom-placed tibial tunnel, confirmation of no roof impingement, and firm fixation of the graft to bone—which can be achieved for long as well as short grafts by fixing the graft within the tibial tunnel—offers an alternative technique and graft tissue for ACL reconstructions. This technique and the preference for double-looped hamstring tendon graft tissue have been effective and successful in more than 200 cases performed by one surgeon (SMH) for a period of 6 years. Aggressive, brace-free rehabilitation is safe with prevention of roof impingement and use of the double-loop hamstring fixation technique.

KEY WORDS: knee, ligament, notch impingement, reconstruction

Our studies1-6 show that graft stretch-out is caused by impingement of the anterior cruciate ligament (ACL) graft at the intercondylar roof. The stretch-out is not related to the graft material. In my experience, the combined double-looped gracilis and semitendinosus autogenous tendon autograft for ACL reconstruction is predictably successful when the graft is placed without roof impingement and is fixed firmly. Since 1986 I have used these tendons for grafts in more than 200 ACL reconstructions. There are several misconceptions about the use of hamstring tendons for ACL grafts. The first is that the mechanical properties of a hamstring graft are insufficient to stabilize a knee predictably. The second is that hamstring grafts have a tendency to stretch out over time.

The third is that fixation of soft tissue to bone is not strong enough for early aggressive rehabilitation. Each of these misconceptions has been counteracted by scientific studies.

An analysis by Marder et al7 of biomechanical data of different graft materials, as published by Noyes et al,8 suggested that a combined double-looped semitendinosus and gracilis graft configuration may have a higher ultimate load-to-failure than a 10-mm wide patellar tendon graft. After studying the data from Noyes et al,8 I have determined that a combined double-looped gracilis and semitendinosus graft should theoretically result in a load-to-failure of 238% of the normal ACL compared to 120% for a 10-mm wide patellar tendon graft. Woo and Adams9 argued that for a graft to be effective it should also recreate the stiffness of the normal ACL. One of the advantages of the hamstring tendon is its stiffness, which is almost identical to that of the normal ACL, in contrast to the patellar tendon graft, which has the disadvantage of being three to four times as stiff.9 In reference to the second misconception, both hamstring and patellar tendon grafts routed through tibial tunnels placed eccentrically or anterior to the slope of the intercondylar roof have an increased incidence of graft stretch-out, resulting in recurrent instability caused by roof impingement (Fig 1).1,2 Stability is superior in knees with unimpinged graft.1,2 The tibial tunnel can be the key to preventing impingement if it is in an unimpinged location when the graft is aligned posterior and parallel to the slope of the intercondylar roof in the maximally
extended knee. The location of the tibial tunnel should be customized to account for individual variations in knee hyperextension and the slope of the intercondylar roof. Third, several investigators have compared the pull-out strength of hamstring-to-patellar-tendon-bone fixation in cadaver studies. The failure load of hamstring fixation by two ligament washers and screws with a figure-eight weave and double-staple belt-buckle technique was similar to bone-to-bone fixation with the use of interference screw.

This article presents a technique for avoiding roof impingement by customizing the location and orientation of...
SURGICAL TECHNIQUE

Patient Positioning

Position the patient supine, and place a well-padded tourniquet proximal on the thigh. The distal two thirds of the thigh must be accessible to allow exposure of the lateral femur and drilling of the femoral tunnel. Access is achieved by placing the proximal thigh and tourniquet in a legholder. The operative leg can be flexed from hyperextension to approximately 100° of flexion by breaking the foot of the operating table. The normal leg is secured to a legholder.

Harvesting the Graft

Harvest of the autogenous semitendinosus and gracilis tendons and drilling of the tibial tunnel are accomplished through a 4- to 5-cm incision. The medial joint line is identified, and a point three finger-breadths distal to the joint line is marked midway between the anterior tibial crest and the posteromedial margin of the tibia. The 4- to 5-cm longitudinal incision is centered on this mark. A tourniquet is used for hemostasis.

The gracilis tendon is the most distinct tendon and is easily palpated deep to the overlying sartorius fascia. An incision is made parallel and inferior to the gracilis tendon by cutting through the expansion of the sartorius insertion. Too deep an incision may cut the medial collateral ligament. Place the knee in flexion to reduce tension in the tendon. Blunt finger dissection is used to separate the tendon from the surrounding tissue, and a 3/8-inch Penrose drain is passed around the gracilis tendon for isolation and gentle traction.

The gracilis tendon is detached subperiosteally from the anterior tibial crest to preserve maximum length. A knife is used to outline the insertion of the gracilis tendon, and the insertion is elevated subperiosteally to gain 2 cm of additional length. The end of the tendon is grasped with an Allis clamp, and a continuous crisscrossing stitch of undyed 1-vicryl (Ethicon Inc, Somerville, NJ) captures 4 cm of the detached tendon stump. The suture must be left at least 25 to 30 cm long to facilitate passage of the graft. With the knee in flexion, finger dissection and scissors are used to free the gracilis tendon from branches of the tendon that course inferior and posterior into the popliteal fossa. Failure to identify and remove these branches may cause the tendon stripper to follow the wrong pathway and prematurely amputate the graft. Gentle tugging on the sutured end of the graft should be repeated until the tendon can be seen to move freely within the incision and to draw the skin overlying the popliteal fossa. A closed-end tendon stripper (Acufex Microsurgical, Norwood, MA) is used to remove the tendon from the muscle belly. The gracilis tendon is identified by muscle tissue on both sides of the tendon.

The same technique is used to isolate and remove the semitendinosus tendon, which lies distal and deep to the gracilis tendon. A dyed 1-vicryl suture is sewn on the subperiosteal end of the semitendinosus tendon to distinguish between the two tendons. In contrast to the gracilis tendon, muscle is present on only one side of the semitendinosus tendon.

Preparation and Final Sizing of the Graft

A periosteal elevator is used to scrape the muscle fibers from each tendon. The semitendinosus tendon is then tubulated by using a running 3-0 undyed vicryl. The color-coded 1-vicryl crisscrossing stitch is used to secure the opposite ends of each graft. A 3-mm wide umbilical tape is looped around the midpoint of both tendons through calibrated cylinders (Arthrotec, San Dimas, CA) to size the graft. The correct diameter for reaming is obtained when the double-looped graft fits snugly in the sizer. Both grafts are submerged in saline.

Establishing Portals

Portal placement must be precise to allow proper positioning of the instruments within the notch. First, outline the inferior tip of patella and medial and lateral edge of the patellar tendon with a marking pen. Then make a lateral portal at a location one third the width of the patella. The impingement-free tibial guide system cannot be positioned in the notch if the anteromedial portal does not lie directly against the medial edge of the patellar tendon. An inflow cannula is placed medially in the suprapatellar pouch to avoid interfering with the exposure of the lateral femur.

Preparation of the Notch

The intercondylar notch must be widened to prevent side-wall impingement of the graft and to improve visualization. An angled osteotome (Arthrotec, San Dimas, CA) is used to remove 3 to 5 mm of the lateral condyle. Bone is not removed from the intercondylar roof at this time. A motorized shaver is used to remove retained synovium and remnants of the anterior cruciate ligament. Preparation is complete when a probe can be used to palpate the proximal (posterior) edge of the intercondylar roof with clear, unobstructed visualization.

Selection of the Site for Femoral Guide Pin Placement

The reference point for determining the location of the intra-articular entrance point of the femoral guide pin is the proximal (posterior) arch of the intercondylar notch.
An angled cervical curette (no. 4) is passed through the medial portal until the angled tip cradles the proximal edge of the intercondylar notch in the over-the-roof position. The tip of the curette is slid forward 6 to 7 mm from the posterior edge and oriented at 11 o’clock for the right knee and 1 o’clock for the left. A 4- to 5-mm recess is made with the angled cervical curette to accept the tip of the femoral guide.

**Tibial Guide Pin Placement**

The location and inclination of the tibial tunnel must be customized to account for individual variations in the slope of the intercondylar and hyperextension of the knee. A knee that hyperextends and/or has a vertical intercondylar roof requires a more posterior tibial tunnel than a knee that extends to zero and/or has a horizontal slope to the roof. The technique for custom placement of the tibial tunnel begins by inserting a transverse drill guide (Arthrotec, San Dimas, CA) through the anteromedial portal into the notch (Fig 2). The cross bar of the transverse guide is oriented so that it is perpendicular to the long axis of the tibia. The recess on the guide is seated at the chondroosseous surface of the distal (anterior) edge of the intercondylar notch. Adjusting knee flexion to 30° to 50° aligns the tip of the guide against the intercondylar roof (Fig 3). Secure the aimer handle to the guide, and drill a smooth 5/64-inch K-wire through the lateral femoral condyle and into the lateral edge of the posterior cruciate ligament (PCL). The transverse guide is disassembled and removed from the notch.

The intercondylar roof guide (Arthrotec, San Dimas, CA) is then brought into the joint through the anteromedial portal with the knee in 70° to 90° of flexion (Fig 4). Its tip is hooked over the transverse pin, and the knee is slowly extended while the guide is advanced into the notch. The transverse pin prevents the roof guide from falling away from the roof. The tip of the roof guide must remain against the intercondylar roof with the arm of the guide flush against the articular surface of the trochlea. All irrigation fluid is removed from the joint, and the heel is placed on a Mayo stand. The surgeon gently forces the knee into maximum passive hyperextension. The roof guide is lifted so that it abuts the intercondylar roof while the hypothenar
eminence of the surgeon’s hand forces the patella posteriorly. The sharp-tipped bullet is secured in the drill guide, and a 2.4-mm threaded pin is drilled with the knee in maximum hyperextension. The trajectory of the pin is customized to lie 4 to 5 mm posterior and parallel to the slope of the intercondylar roof in the maximally extended knee.

**Drilling the Tibial Tunnel**

Step reaming of the tibial tunnel is required to use the tibial fixation guide. The outer 20 mm of the tibial tunnel is reamed first with an 11-mm cannulated reamer, and the remainder of the tibial tunnel is completed by reaming with the cannulated reamer sized for the combined diameter of the double-looped hamstring graft. Reamings are collected to be used later for bone grafting the tibial tunnel.

**Assessing and Eliminating Roof Impingement**

Impingement between the graft and intercondylar roof cannot be seen with the knee in maximal hyperextension. The graft-roof relationship is simply out of the surgeon’s view in the extended knee. An indirect technique has been developed to detect roof impingement before graft implantation (Fig 5). An impingement rod (Arthrotec, San Dimas, CA) with the same diameter as the tibial tunnel is inserted into the tibial tunnel with the knee in maximum hyperextension. Roof impingement exists if the rod does not freely pass into the notch. The knee is then slowly flexed until the rod passes into the notch. This difference in knee extension demonstrates the flexion angle at which graft-roof contact would take place if a portion of the roof is not removed.

I always perform a roofplasty to insure that the volume of the notch can easily accommodate the graft (Fig 6). Clearance should be at least 3 mm with the knee passively extended to provide enough clearance when the tibia translates anteriorly during active knee extension. The knee is redistended, and a curved gouge (Arthrotec, San Dimas, CA) is brought into the notch through the anteromedial portal with the knee in 35° to 40° of flexion. Articular cartilage and cortical bone are removed from the intercondylar roof, and the roofplasty is tapered proximally using a motorized burr. Successful elimination of roof impingement can be assured when the impingement rod freely passes into the notch with the deflated knee in maximum, passive hyperextension (Fig 7).

**Drilling the Femoral Tunnel**

A 5-cm anterolateral incision is used to expose the lateral femur. Either a rear entry or front entry femoral guide system (Acufex Microsurgical, Norwood, MA) can be used to drill the femoral guide pin. The tip of the guide is placed in the 4- to 5-mm recess in the roof made by the angled cervical curette, and the guide pin is drilled. The guide pin should enter the notch 5 to 7 mm distal to the proximal edge of the intercondylar roof at 11 o’clock or 1 o’clock for the right and left knee, respectively. The tunnel

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is reamed, and the inner edge is chamfered to remove sharp edges.

Inserting the Tibial Fixation Screw

Approximately 25% of the double-looped hamstring grafts are too short for firm fixation if they are secured to bone outside both the femoral and tibial tunnel. A method has been devised to fix the graft within the tibial tunnel, which preserves graft length and allows short grafts as well as longer grafts to be anchored. The tibial fixation device (Arthrotec, San Dimas, CA) centers and recesses a screw 15 mm inside the tibial tunnel (Fig 8). The screw functions as a fixation post.

The setup for implantation of the graft requires two 3-mm wide umbilical tapes that are closed into a loop by knotting their free ends. A no. 14 red rubber catheter is threaded through the tibial tunnel, into the notch, and out through the femoral tunnel. The knotted ends of the umbilical tapes are passed through a 10-mm slot cut in the side wall at the tibial end of the catheter, and the two looped umbilical tapes are drawn through the joint. The umbilical tapes are removed from the catheter.

The tibial fixation guide is assembled by placing the superstructure containing the large and small drill sleeves on the long centering rod. The umbilical tapes are aligned along opposite sides of the centering rod and looped over each of the perpendicular metal posts on the tibial fixation guide. The umbilical tapes must be recessed in the grooves on either side of the tip of the centering rod to insure that the tapes are on opposite sides of the fixation screw. The tibial fixation guide is inserted into the 11-mm reamed tibial tunnel, and the guide is rotated so that drilling will be perpendicular to the anteromedial flare of the tibia. The umbilical tapes are snugged by pulling on the portion exiting the femoral tunnel. A 2.7-mm drill is used to drill across the entire width of the tibia. The small drill sleeve is removed, and the near tibial cortex is tapped with a 4.0-mm tap placed through the large drill sleeve. The superstructure is removed without rotating the centering rod within the tibial tunnel. The depth of the tapped and drilled hole is measured. A specially designed low-profile 4.0-mm cancellous screw is inserted to gain firm purchase on the posterior tibial cortex. The tibial fixation guide is withdrawn from the tibial tunnel, leaving the two umbilical tapes on opposite sides of the tibial fixation screw.

Passing the Graft

A third umbilical tape is looped around the midpoint of the semitendinosus and gracilis tendon grafts. One of the sutured ends of the gracilis and semitendinosus tendons are passed through one of the two transarticular umbilical tapes, and the sutures on the opposite ends of the grafts are passed through the other umbilical tape. The umbilical tapes are used to pull the sutured ends of each of the two grafts through the tibial tunnel and the intercondylar notch and out through the femoral tunnel. The tendons are then individually adjusted to even their length, and the graft is drawn through the joint. If hang-up occurs, the third umbilical tape can be used to back the graft out of the tibial tunnel away from the tibial fixation screw to assist in working the snugly fitting graft through the knee. The looped end of the two grafts should rest snugly around the smooth shank of the recessed tibial fixation screw. The umbilical tape about the midpoint of the looped grafts is then cut and removed.

Pretensioning the Graft

Tension is applied individually to each end of the two grafts, and the knee is cycled in flexion and extension 20 times to be certain that the grafts are not hung-up on the
Tunnel reamings are used to bone graft the tibial tunnel. Graft excursion is checked by the surgeon holding all four grafts ends with tension and palpating the junction of the femoral tunnel and graft with the index finger while the knee is taken through a range of motion. When properly placed, the graft should slide no more than 1 to 2 mm out of the femoral tunnel as the knee is brought from 0° to 105° of flexion. This “excursion profile” indicates that the graft will not stretch if it is secured to the femur with the knee in full extension.

Securing the Graft

Fixation of the graft can be done with either a screw and ligament washer or with ligament staples. If screw fixation is used, two 6.5-mm cancellous screws and soft tissue washers are partially screwed into place on the lateral femoral flare. The ends of the two tendon grafts are weaved in a figure-eight fashion about the smooth shaft of the two fixation screws. The screws are tightened, which firmly secures the graft.

Another alternative is staple fixation with a belt-buckle technique (Fig 9). The first staple is placed 15 mm proximal to the femoral tunnel fixing all four graft stands to the femoral shaft. Graft tension is then checked arthroscopically by palpating the graft at 30° intervals from 20° to 80° of flexion before seating the second staple. The graft is then folded back over the first staple toward the femoral tunnel, and a second ligament staple is placed between the femoral tunnel and the first staple. The second staple secures eight bundles of the two tendons.

Closure and Postoperative Management

Tunnel reamings are packed into the tibial tunnel around the graft and the recessed transfixion screw. The 11-mm impingement rod can be used to pack the bone graft around the tendon graft and fixation screw. A 1/8-inch drain is placed intraarticularly through one of the anterior portals. The wounds are closed in layers in a standard fashion, and the dressings are held in place with sterile cast padding and a compression stocking. I have not used a postoperative brace or immobilizer on a patient for 2 years. Continuous passive motion is used in the hospital for 2 days. The majority of patients are crutch free and fully weight bearing by 3 to 4 weeks post-operatively.

COMMENT

Predictable knee stability is best achieved by avoiding roof impingement. Roof impingement is the primary cause of postoperative flexion contractures and graft stretch-out. The impingement-free tibial drill guide system customizes the location and orientation of the tibial tunnel for individual variations in knee hyperextension and slope of the intercondylar roof. The detection of room impingement by an impingement rod is an effective technique for eliminating roof impingement before graft implantation. The combined double-looped semitendinosus and gracilis graft is an excellent graft source for ACL reconstructive knee surgery. The ultimate load-to-failure of this graft configuration theoretically exceeds that of a normal ACL and a central one third patellar graft. The hamstring graft also has the advantage of matching the stiffness of a normal ACL in contrast to the patellar ligament graft, which is three to four times as stiff.

Secure graft fixation to bone can be achieved by recessing the graft within the tibial tunnel. This technique allows short grafts as well as longer grafts to be fixed. The figure-eight weave and double-staple belt-buckle technique have pull-out strengths from the femur similar to that of interference screw fixation of bone plugs within osseous tunnels.

The development of this combination of techniques for inserting and fixing the combined double-looped semitendinosus and gracilis ACL graft has made this graft my preference for an ACL reconstruction. The technique of detection and correction, ie, prevention, of roof impingement described is applicable to ACL reconstruction with tissues other than the hamstring tendons.

REFERENCES