Rationale and Endoscopic Technique for Anatomic Placement and Rigid Fixation of a Double-Looped Semitendinosus and Gracilis Graft

Lt Col Stephen M. Howell, MD, USAFR MC

Summary: The double-looped semitendinosus and gracilis (DLSTG) graft is an excellent autogenous graft for replacing a torn anterior cruciate ligament because of its superior structural properties and minimal harvest morbidity. Customized placement of the tibial tunnel for variability in knee anatomy and avoiding roof impingement improves the clinical outcome and is a prerequisite for aggressive rehabilitation. Anatomic placement of the femoral tunnel can be achieved using an endoscopic technique in which an over-the-top femoral aimer is inserted through a customized tibial tunnel. Rigid fixation of the DLSTG graft is required to safely rehabilitate the knee aggressively without a brace and return the patient to unrestricted sports by 4 months postoperatively. The use of a fixation post with bone compaction inside the femoral tunnel through the implant (Bone Mulch Screw) results in reciprocal tensile behavior of the graft. The use of a multiple-spiked washer (WasherLoc, Arthrotek, Inc, Warsaw, IN, U.S.A.) achieves rigid, countersunk fixation inside the tibial tunnel. Fixation methods that rely on suture bridges or interference screws to fix soft tissue grafts have not been shown in the laboratory to withstand the loads imposed by activities of daily living. When stiff fixation methods are used, graft pretensioning should be performed with the knee in full extension to avoid overconstraining the knee. Key Words: Fixation-Anterior cruciate ligament-Rehabilitation.

WHY USE THE DLSTG GRAFT CONSTRUCT?

Rationale

The surgeon has four decisions to make when deciding how to reconstruct a knee with a torn anterior cruciate ligament (ACL), including which graft to use, how to place the tunnels, which fixation methods to use, and how to pretension the graft. This article discusses the following topics: the rationale for using the double-looped semitendinosus and gracilis (DLSTG) graft; the rationale and technique for placing the tibial and femoral tunnels anatomically; the importance of using rigid fixation methods and the method of implantation; and the factors influencing graft tensioning and a method for pretensioning the graft.

Patients reconstructed with a DLSTG graft and rigid fixation (to be defined later) can be aggressively rehabilitated without a brace and safely returned to unrestricted activities at 4 months (Figs. 1 and 2). Because
the stability at 2 years was unchanged from 4 months, the DLSTG graft was strong and mature enough to tolerate the early return to unrestricted sports and work without a brace.\textsuperscript{6,14,16}

**TIBIAL TUNNEL PLACEMENT**

**Rationale**

For the knee to regain full extension and remain stable, the tibial tunnel must be placed anatomically without roof impingement.\textsuperscript{5,8,9,11,12,15,35} Anatomic graft placement is achieved when all of the graft fibers are aligned within the pathway of the original ACL. The pathway of the normal ACL is determined by the intercondylar roof in the sagittal plane (Fig. 3) and the medial and lateral eminences in the coronal plane according to magnetic resonance imaging (MRI) of the normal ACL.\textsuperscript{13,17} The anterior and posterior limits of the insertion of the normal ACL varies between knees\textsuperscript{31} because the angle formed by the intercondylar roof and long axis of the femur (that is, roof angle) varies greatly from 23-60° and knee extension varies from 30° of hyperextension to 2° of flexion.\textsuperscript{10}

Because the limits and position of the normal ACL insertion are different between knees and are determined by the interrelationship of the slope of the intercondylar roof and knee extension, it follows that the sagittal position of the tibial tunnel can be determined by a guide that references the intercondylar roof with the knee in full extension. Point and shoot guides that reference the ACL insertion are operator-dependent and may place the tibial tunnel too far anteriorly because the native ACL insertion is twice as wide as a 10-mm diameter tibial tunnel.\textsuperscript{13} Anterior tunnel placement can produce flexion contractures, graft abrasion, and instability from roof impingement (Fig. 4).\textsuperscript{15,35} A guide that references the posterior cruciate ligament (PCL) placed the tibial tunnel with an average of 8.5 mm of clearance between the anterior edge of the graft and the intercondylar roof\textsuperscript{24} which was nonanatomic, too posterior, and more vertical compared with the normal ACL (Fig. 5).

**Preferred technique using One-Step Tibial Guide**

The One-Step Tibial Guide (Arthrotek, Inc, Warsaw, IN, U.S.A.) is a tibial aiming device that customizes the location of the center of the tibial tunnel in the sagittal plane to match the pathway of the normal ACL (Figs. 6 and 7). The best accuracy is achieved when the guide is used before expanding the notch by a roof or wallplasty.\textsuperscript{7}

The guide is inserted through an anteromedial portal that touches the patellar tendon. The tip of the guide is positioned between the PCL and the lateral femoral condyle. The knee is hyperextended and maintained in this position by placing the heel on a raised Mayo stand. The guide is seated against the trochlear groove by gently levering the arm of the guide toward the ceiling. Three-point fixation aligns the guide within the notch; the tip rests on the cartilage covering the lateral eminence, the positioning bump is constrained by the intercondylar roof, and the arm of the guide is pressed against the articular cartilage of the trochlear. The guide is oriented in the coronal plane so the guide wire forms an angle of 70-75° with the medial joint line.
Anatomic placement of the tibial tunnel is achieved because the guide positions a provisional guide wire 4-5 mm posterior and parallel to the intercondylar roof with the knee in full extension.\(^7,^9,^{14}\) The 4-5-mm clearance between the wire and intercondylar roof allows the anterior surface of an 8-10-mm diameter graft to lie against the roof with the knee in full extension. In the coronal plane, the guide positions the tibial tunnel anatomically between the medial and lateral eminences.\(^7,^{17,25,29}\)

Because the DLSTG graft is round in cross-section and the apex of the intercondylar notch is narrower than its base, the outlet of the notch must be expanded to avoid conflict between the graft and intercondylar roof with the knee in full extension. Confirmation that the expansion of the roof and wall is sufficient to avoid roof impingement is verified by unobstructed passage of a metal rod (Impingement Rod, Arthrotek, Inc), the same diameter as the graft, through the tibial tunnel and into the notch with the knee in full extension before implanting the graft (Fig. 8).\(^7,^{15,16}\)

**FEMORAL TUNNEL PLACEMENT**

**Rationale**

A potential disadvantage of the endoscopic technique is the inability to freely position the femoral tunnel because it is drilled through the tibial tunnel (Fig. 9). Because femoral tunnel placement determines the tensile behavior of the graft and knee stability,\(^{18,23,27}\) the loss of freedom in placing the femoral tunnel may compromise the clinical result compared with the two-incision technique in which the femoral tunnel is positioned independently from the tibial tunnel.

A clinical study tested this hypothesis and concluded that the endoscopic and two-incision techniques provided similar stability and clinical outcome 2 years postoperatively when the knee was reconstructed using a DLSTG graft and rehabilitated intensively without immobilization or a brace. In both treatment groups the position of the tibial tunnel was customized, complications from roof impingement were prevented, and the graft was fixed directly to bone without sutures. The endoscopic technique of drilling the femoral socket through the customized tibial tunnel did not compromise the clinical results and was the preferred technique because it was more cosmetic and quicker to perform (average operative time 68 minutes).\(^6\)
Preferred technique using size-specific femoral aimers

Remove the ACL origin from the over-the-roof position using a cervical curette. This allows the tip of the femoral aimer to rest on bone instead of soft tissue which prevents the drill from breaking through the posterior wall of the femoral socket. Insert the femoral aimer with the size that matches the diameter of the graft through the customized tibial tunnel (Size Specific Femoral Aimer, Arthrotek, Inc) and hook it in the over-the-roof position (Fig. 9). The femoral aimers are designed to retain 1-2 mm of bone on the posterior wall of the femoral tunnel. The knee is flexed which locks the guide in position. The guide is rotated so that the tip of the aimer is positioned at the 10:30 to 11:00 position for the right knee or 1:00 to 1:30 for the left knee. Insert a provisional guide pin, check its placement, and drill a 25-mm length closed-end femoral socket that matches the diameter of the DLSTG graft.

**FIXATION REQUIREMENTS FOR AGGRESSIVE REHABILITATION**

Fixation of a DLSTG graft should be strong enough to avoid failure, stiff enough to maintain stability, and slip minimally under cyclic loads\(^{14,20}\) until the strength of the biologic fixation stabilizes, which requires 3 months.\(^{28}\) The estimated load in the ACL during activities of daily living is 500 N.\(^{4}\) Therefore, tibial and femoral fixation methods selected for use with aggres-
sive rehabilitation should provide “rigid fixation” with a strength greater than 500 N, stiffness within the range of the normal ACL (200-300 N/mm), and slip no more than 2 mm during cyclic loading up to 500 N of load.\(^{14,20}\) These fixation structural properties must be met in tests using human bone because they are overestimated in more dense animal bone.\(^{20}\)

**ENDOSCOPIC FEMORAL FIXATION**

**Rationale**

The Bone Mulch Screw (Arthrotek, Inc) is an endoscopic femoral fixation method for the DLSTG graft that provides structural properties in human bone that meet the performance criteria for aggressive rehabilitation (Figs. 1 and 2). The implant is countersunk within the lateral femoral condyle to avoid symptoms from hardware prominence. The graft is fixed by looping both tendons around the post extending from the hollow body. The post is positioned 18 mm inside a 25-mm length closed-end femoral socket.

The Bone Mulch Screw-human femur-DLSTG graft fixation complex failed at 1126 ± 80 N and provided a stiffness of 225 ± 23 N/mm which is within the range of the normal ACL (Fig. 10). Compaction of bone into the femoral tunnel through the bore in the center of the implant provided 41 N/mm of the stiffness.\(^{32}\) Bone compaction also induced reciprocal tensile behavior of the anterior and posterior bundles of the DLSTG graft similar to the anteromedial and posterolateral bands of the normal ACL. Reciprocal tensile behavior of the graft required a rigid post spanning an endoscopic femoral tunnel placed through a customized tibial tunnel and did not require two separate femoral sockets.\(^{33}\) Slippage of the fixation was minimal because subsidence was prevented by the large diameter (10.5 mm) of the implant.

Other endoscopic femoral fixation methods that have been tested, including buttons (EndoButton; Smith and Nephew Endoscopy, Andover, MA, U.S.A.; strength = 430 N, stiffness = 23 N/mm), anchors (Mitek Ligament Anchor; Mitek Surgical Products, Nor-wood, MA, U.S.A.; strength = 312 N, stiffness = 25 N/mm),\(^{32}\) and soft tissue interference screws (strength = 354 N, stiffness = 68 N/mm, slippage = 4.5 mm),\(^{19}\) do not provide enough rigid fixation for aggressive rehabilitation in my opinion. The elastic suture bridge was the cause of the low stiffness of the button and anchor (that is, one tenth of the normal ACL).\(^{32}\) Graft incorporation may be

---

**FIG. 8.** The clearance between the graft and the inter-condylar roof can be difficult to view with the knee in maximum extension. Inserting a metal rod the same diameter as the graft through the tibial tunnel and into the notch with the knee in maximum extension can confirm that the expansion of the notch is sufficient to avoid impingement.

**FIG. 9.** Endoscopic femoral tunnel placement is accurate with a femoral aimer that is inserted through the tibial tunnel and hooked in the over-the-roof position. To avoid breaking through the back of the femur when reaming the femoral tunnel, all soft tissue should be removed between the tip of the aimer and bone. After inserting a guide wire, a 25mm length closed femoral socket is drilled that matches the diameter of the DLSTG graft.
impaired during aggressive rehabilitation because the elasticity of the suture causes substantial graft-tunnel motion (that is, 3-5 mm).\textsuperscript{37}

**Preferred technique using Bone Mulch Screw**

The U-guide (U-Shaped Drill Guide; Arthrotek, Inc) is inserted into the femoral tunnel retrograde through the tibial tunnel (Fig. 11). The U-guide is used to drill a 2.4-mm wire through the lateral femoral condyle entering 18 mm inside and bisecting the femoral tunnel. An 8-mm cannulated reamer is used to drill the tunnel for the Bone Mulch Screw.

The reamings are saved. The anterior and posterior walls of the femoral tunnel are expanded using the tunnel router (Arthrotek, Inc) (Fig. 12). The Bone Mulch Screw is inserted two-thirds across the femoral tunnel. A suture is passed around the post using a suture loop passer (Arthrotek Inc). The tip of the implant is advanced 2-3 mm into the medial wall of the femoral tunnel (Fig. 13). The suture is tied to the suture sewn to the DLSTG graft and the graft is pulled around the post and through the knee.\textsuperscript{7} The expansion of the femoral tunnel at the level of the post by the tunnel router facilitates passage of the graft.

**TIBIAL FIXATION**

**Rationale**

The WasherLoc countersunk tibial fixation device (Arthrotek, Inc) provides enough rigid structural properties in human bone that meet the performance criteria for aggressive rehabilitation. The WasherLoc is recessed beneath the anterior tibial cortex inside the tibial tunnel to avoid symptoms from hardware prominence (Figs. 1 and 2). To prevent the graft from extruding from under the implant, the four tendons are contained between the four long, large-diameter peripheral spikes (Fig. 14). The two distal spikes gain purchase in cortical bone. The 13 shorter, narrower spikes penetrate each graft bundle in several locations providing multiple sites of fixation.

The WasherLoc-human tibia-DLSTG graft fixation complex failed at 905 N (range, 544-1287 N) with a stiffness of 273 ± 56 N/mm which is within the range of the normal ACL, and slipped less than 2.0 mm at cyclic loads to 500 N.\textsuperscript{20} Other tibial fixation methods that have been tested in porcine tibia (best case analysis), including sutures tied to a post strength = 442 N, stiffness = 60 N/mm, slippage = 4.9 mm at 500 N) (No. 5 Ethibond; Ethicon Inc, Cincinnati, OH, U.S.A.), double staple fixation (strength = 785 N, stiffness = 118 N/mm, slippage = 3.3 mm at 500 N) (regular fixation staples; Smith & Nephew Richards, Memphis, TN, U.S.A.), and a 20-mm washer (strength = 724 N, stiffness = 126 N/mm, slippage = 3.5 mm at 500 N) (spiked washer; Linvatec, Largo, FL, U.S.A.), did not provide the required fixation structural properties for aggressive rehabilitation.\textsuperscript{20}

Interference screw fixation of a double-looped bovine tendon graft performed well in porcine tibia (strength = 598 N, stiffness = 226 N/mm, slippage = 0.7 mm at 500 N) but was significantly worse with a DLSTG graft in young human tibia (strength = 350 N, stiffness = 248 N/mm, slippage 3.7 mm at 500 N) and did not meet

\textsuperscript{20}
the rigid fixation criteria for use with aggressive rehabilitation (9 x 25 mm standard interference screw; Smith & Nephew Donjoy, Carlsbad, CA, US.A.). Studies that evaluated titanium and bioabsorbable interference screw fixation of a three-stranded semitendinosus graft in bovine tibia demonstrated pull-out force and stiffness properties that were also not rigid enough for aggressive rehabilitation. The pull-out force was 419 N (range, 316-558 N) for a round-headed interference screw (RCI; Smith & Nephew Donjoy, Carlsbad, CA, U.S.A.) and was 507 (range, 332-647 N) for a biodegradable interference screw. The stiffness was 40 and 58 N/mm for each method, respectively, only 25% of the normal ACL.

Preferred technique using WasherLoc countersunk tibial fixation device

A counterbore is drilled at the distal end of the tibial tunnel using the counterbore reamer (Arthrotek Inc) (Fig. 15). The graft is tensioned with the knee in full extension. Screw the driver into the threaded hole in the WasherLoc (Fig. 16). The WasherLoc is positioned so that the DLSTG graft is contained between the four peripheral spikes and the implant is driven into the tibia allowing the shorter spikes to penetrate and compress

FIG. 12. Two millimeters of the anterior and posterior wall of the femoral tunnel are removed using the tunnel router. Creating a little more clearance between the post of the Bone Mulch Screw and the tunnel wall facilitates passage of the graft.

FIG. 13. A loop of suture is passed around the tip of the Bone Mulch Screw. The screw is further advanced until the tip of the post is embedded 2-3 mm inside the medial wall of the femoral tunnel. The suture is then used to pull the DLSTG graft into place.

FIG. 14. The multiple fixation spikes are responsible for the strength, stiffness and minimal slippage of the WasherLoc fixation. The graft is contained by the four larger-diameter peripheral spikes, the distal two of which purchase in dense cortical bone. The 13 smaller-diameter, more central spikes penetrate the graft in multiple locations which prevents slippage.
the graft against the posterior wall of the tibial tunnel (Fig. 17). A 3.2-mm hole is drilled through the tibia, the depth is measured, and a self-tapping WasherLoc screw is inserted engaging the posterior cortex of the tibia (Figs. 1 and 2).

PRETENSIONING THE GRAFT

Rationale

Just as the strength of a graft-fixation complex at the time of implantation is determined by the strength of the fixation method, so is the stiffness. The reduction in the stiffness of the ligament replacement is caused by fixation methods being less stiff than the DLSTG graft.\textsuperscript{20,32}

Fixation methods with lower stiffness or more elasticity require a higher pretension to stabilize the knee. For example, tension in a BPTB graft, with an estimated stiffness of 18-28\% of the normal ACL (51 N/mm),\textsuperscript{30} was threefold greater than in the intact ACL when it was pretensioned to restore normal anterior-posterior laxity.\textsuperscript{21} Unfortunately, fixation methods with lower stiffness (that is, suture bridges, double staples, single washer and screw, interference screw) in general fail at lower loads and slip more than fixation methods with higher stiffness (Bone Mulch Screw, WasherLoc). The problem, therefore, is that low stiffness fixation methods require higher pretension to restore stabil-ity but are least capable of resisting failure and slippage at the higher forces.\textsuperscript{20}
The maximum tension in the normal ACL\textsuperscript{21,33} and a properly placed ACL graft\textsuperscript{21,33} occur with the knee in maximum extension with little or no tension between 15° and 90° of flexion. With this pattern of tensile behavior, greater increases in graft force are produced by changing the flexion angle at tensioning from 0-30° rather than by increasing the initial tension.\textsuperscript{2} Therefore, if the goal is to restore normal laxity and match the forces in the graft-fixation complex to that of the normal ACL, the fixation methods should, when attached to the graft and bone, provide a stiffness similar to the normal ACL and the graft can be pretensioned with the knee in full extension to avoid overconstraining the knee.

**Preferred technique**

The stiffness of the DLSTG graft fixed with the Bone Mulch Screw\textsuperscript{32} and WasherLoc\textsuperscript{20} has a stiffness similar to the normal ACL. Therefore, pretension should not be applied to the graft with the knee in flexion or the knee may become overconstrained.

To avoid limiting flexion and extension, the graft-fixation complex is pretensioned with the knee in maximum extension. An unmeasured force is applied to the graft exiting the tibial tunnel and the WasherLoc fixation is completed. Palpation of the graft with a probe as the knee is moved from extension to 30° of flexion usually demonstrates a slight increase in slackness in the graft which is physiological and similar to the tensile behavior of the normal ACL.\textsuperscript{22}

**CONCLUSION**

The DLSTG graft is an excellent autogenous graft because of its excellent structural properties and minimal harvest morbidity. The success of any ACL reconstruction is dependent on anatomic placement of the femoral and tibial tunnels. Customized placement of the tibial tunnel for variability in knee anatomy and avoiding roof impingement improves the clinical outcome. Anatomic placement of the femoral tunnel can be achieved using the endoscopic technique and an over-the-top aimer. Rigid fixation of the DLSTG graft is required to safely and aggressively rehabilitate the knee and return the patient to unrestricted sports at 4 months. The use of a fixation post with bone compaction inside the femoral tunnel through the fixation device results in reciprocal tensile behavior of the graft. Graft pretensioning should be performed with the knee in full extension to avoid overconstraining the knee when fixation methods are used that reproduce the stiffness of the normal ACL.

**REFERENCES**


