Abstract: Hamstring autografts in anterior cruciate ligament reconstruction have an excellent clinical track record, but some patients have hamstring tendons that yield grafts of smaller diameter, which has been shown to be a significant risk factor for worse outcomes and graft failure. Some authors have advocated augmentation with allograft in these patients. Tripling the semitendinosus yields a completely autogenous 5-strand graft with a larger diameter but still of sufficient length. In addition, imaging studies still show signal heterogeneity within grafts, even autografts, after the healing process, which correlates with worse biomechanical properties. Recent animal studies have shown improved incorporation and better remodeling of soft tissue grafts with the use of an endogenous fibrin clot. We present our technique of biologic and mechanical augmentation of hamstring autografts with fibrin clot and a 5-strand graft.

Anterior cruciate ligament (ACL) tears are a common injury in the athletic population, and autografts are more commonly used than allograft because of their lower risk of failure and revision surgery.1,2 Hamstring autograft is one of the most common graft choices; however, when creating a 4-strand construct, some patients have tendons that yield smaller-diameter grafts,3 which have been shown to be strongly correlated with the risk of graft failure and worse patient-reported outcomes.4,5 Rather than augmenting a 4-strand hamstring autograft with allograft tissue, we prefer to triple the semitendinosus to yield a 5-strand autograft.

In addition, imaging studies have shown that ACL grafts often show heterogeneity on magnetic resonance imaging, which correlates with worse biomechanical properties.6 Incorporating an endogenous fibrin clot into the graft construct in a caprine model has shown improved graft vascularity, increased amount of Type I collagen, and improved homogeneity on magnetic resonance imaging.7 In addition, it is a universally available, free method of biologic augmentation of ACL reconstruction that requires little extra time.

Here we describe a simple technique of fibrin clot preparation and incorporation, as well as a simple technique to prepare a 5-strand hamstring autograft.

Technique

Tendon Harvesting

A longitudinal incision is made over the hamstring insertion, which is palpated by rolling one’s fingers over the medial tibia, and the sartorial fascia is exposed using blunt dissection. After palpating the tendons again, a horizontal incision is made in the fascia proximal to the gracilis, and extended distally in an L. The gracilis is isolated and detached as far anteriorly as possible. An Allis clamp is placed on the free end, and a no. 2 Ultrabraid (Smith & Nephew, Andover, MA) is used to secure the tendon using a Krackow configuration, with 4 to 6 passes proximally and distally, ensuring all slack is removed prior to each subsequent pass. Each pass should be at a slightly different point around the tendon to capture different fibers and minimize the risk of suture slippage through the tendon. An Army-Navy retractor is placed inside the fascia, and, using the sutures for traction, the adhesions are carefully and completely dissected off the tendon circumferentially as
far proximally as possible. A blunt-tipped retractable tendon stripper (Stryker, Greenwood Village, CO) is used to harvest the tendon. If excessive force is required, the tendon should be reexamined for adhesions and freed. It is critical to avoid premature amputation of the tendons, particularly the semitendinosus, as it is to be tripled during graft preparation. Once harvested, the surgeon himself or herself takes the tendon to the back table and places it in a moist sponge to minimize handoffs and the risk of dropping the graft. The same is repeated for the semitendinosus, which is typically larger and has more robust adhesions.

**Graft Measurement**

We plan for at least 20 mm, preferably 25 mm, of tendon within each tunnel, and 29 to 35 mm intra-articularly, resulting in a graft of roughly 70 to 85 mm. Each tendon is placed on the graft board. Using the flat edge of a metal ruler or osteotome, the muscle is debrided. To obtain a graft at least 80 mm long, each tendon must be sized at least 5 mm longer for each fold: the gracilis (folded once) is cut at 16.5 cm, and the semitendinosus (folded twice) is cut at 25 cm, ensuring each is of sufficient thickness at those lengths. The proximal ends of the tendons flatten, but because they will be tubularized later, the surgeon should roll each tendon between his or her fingers to verify thickness. Although at least 80 to 85 mm is optimal, the graft can be as short as 70 mm, still leaving 20 mm in each tunnel. The previously placed sutures on the semitendinosus are held apart (Fig 1A), and the tendon is then folded back on itself between the 2 sutures, evening out its 3 limbs (Fig 1B). The gracilis is placed between the same sutures, evening out its 2 limbs. The sutures on the semitendinosus are used to pull the 5-limb graft through a sizing block to assess diameter (Fig 1C). The
femoral tunnel is typically drilled 0.5 mm larger and the tibial tunnel is drilled 0.5 to 1 mm larger to account for the fibrin clot and the final sutures. The tibial end of the graft can be remeasured after final graft preparation and before drilling the tunnel.

Graft Preparation
Another no. 2 Ultrabraid Krackow is placed on the proximal end of each tendon. Once the appropriate length is chosen for the EndoButton CL Ultra (Smith & Nephew), it is secured on the graft board. The distal end of the semitendinosus is tied to the loop with 7 square knots. It is then passed through the EndoButton loop, evening out the 3 limbs. A suture (no. 0 Vicryl, Ethicon, Somerville, NJ) is passed through the fold of the tendon. This is used to pull traction to keep all 3 limbs under tension (Fig 2A). Another no. 2 Ultrabraid Krackow is placed at the folded end of the tendon, capturing both limbs with the suture (Fig 2B). The gracilis is also passed through the EndoButton loop (Fig 2C).

Fibrin Clot Preparation
Fifty milliliters of venous blood are obtained and transferred into a specimen cup on the surgical field (Fig 3A). To create a clot, the blood must be mechanically agitated. We have used 2 techniques successfully. The first is stirring the blood with a metal rod, such as a narrow Cobb elevator. This requires 10 to 15 minutes of agitation. The second is placing a metal object, such as a spare valve from a metal arthroscopic portal, into the cup and shaking it, typically for less than 5 minutes. The clot is then scooped out onto a clean dry surgical towel and is squeezed dry, leaving the solid fibrin clot behind. It often appears as a mesh and must be compiled into a solid mass (Fig 3B).

Fibrin Clot Incorporation
The fibrin clot is carefully placed between the bundles of the graft in the femoral and intra-articular portions. We use a no. 2 Ultrabraid to tie a figure-of-8 around the femoral portion of the graft, leaving 2 long tails that are passed around the graft in opposing directions in a spiral fashion, creating a “finger trap” around the graft to compress the final construct and maintain the fibrin clot between the bundles (Fig 3C). The circumferential sutures should pass proximally to encompass the entire proximal end before progressing distally. Another knot is tied just proximal to the distal end of the

Table 1. Advantages and Disadvantages

| Advantages                                      | Disadvantages                                      |
|------------------------------------------------|---------------------------------------------------|
| The 5-stranded graft is biomechanically stronger than a 4-stranded graft | Premature amputation of the hamstring tendons may preclude use of this technique |
| Use of a 5-stranded graft minimizes the chance of having a graft of insufficient diameter, which has been shown to be associated with worse outcomes and a greater risk for failure | Preparing a 5-stranded graft requires increased time |
| The fibrin clot leads to better incorporation of the graft, with better vascularity and more Type I collagen | Preparing the fibrin clot and incorporating it requires increased time |
| A fibrin clot is cheap, easy to incorporate, and universally available from all patients |                                                   |
Free all adhesions from both the gracilis and semitendinosus prior to harvest. Take care to harvest the full length of both tendons, particularly the semitendinosus. Even out the limbs of the tripled semitendinosus to ensure each limb is tensioned appropriately. When initially measuring graft diameter to determine tunnel diameter, account for the increased diameter of the fibrin clot and additional sutures: 0.5 mm on the femoral side, and 0.5-1.0 mm on the tibial side. Place a circumferential suture around the femoral and intra-articular portions of the graft to contain the fibrin clot. The intra-articular portion to avoid interfering with the interference screw that will eventually separate the strands of the graft.

In this case (Video 1), the patient was still skeletally immature, so we choose not to place an interference screw on the tibial side, and instead, used suspensory fixation with another EndoButton. As a result, we could place fibrin clot and continue the circumferential sutures on the tibial portion of the graft, as well. At this point, the graft is fully prepared. It is placed under 5 pounds of tension on the graft board and wrapped in a clean, moist sponge until insertion.

**Discussion**

Hamstring autograft is an increasingly popular graft choice in ACL reconstruction. It is typically created using a 4-strand construct, which can sometimes yield grafts of smaller diameter. Smaller-diameter grafts have been shown to be a risk factor for graft failure and worse patient-reported outcomes.\(^4,5,8\) Rather than augmentation with allograft, we prefer to triple the semitendinosus to yield a 5-strand graft of larger diameter that is still entirely autograft. In addition, attempts at biologic augmentation of ACL grafts have yielded mixed results, but the incorporation of an endogenous fibrin clot into the graft has shown promising results in a caprine model, with improved vascularity, increased Type I collagen, and improved graft homogeneity on magnetic resonance imaging.\(^7\)

Because of the additional strand of tendon, this method of preparation yields a hamstring autograft that is stronger than a traditional hamstring graft. This method also mitigates the risk of having a smaller diameter graft, which has been shown to be a risk for poor outcomes and graft failure. In addition to improving the mechanical environment of the reconstruction, the fibrin clot improves the biologic environment. This is a simple, cheap method that has shown significant promise in improving graft incorporation (Table 1). However, these additional attempts to improve the mechanical and biologic aspects of the graft do require extra time in graft preparation. The surgeon may have to take some time preoperatively and/or intraoperatively to train his or her assistant to prepare a 5-strand graft with an incorporated fibrin clot. And premature amputation of the tendons, particularly the semitendinosus, may preclude use of this technique (Table 2).

We believe our technique of fibrin clot preparation and incorporation, combined with our technique of 5-strand graft preparation, is easy, reproducible, and requires little extra time or expense. We believe that this combined technique provides both biologic and mechanical augmentation of ACL grafts to maximize graft strength, and improve graft incorporation and maturation. As a result, we believe that using a 5-strand graft has the potential to lead to better patient-reported outcomes with a lower risk of graft failure.

**Table 2. Technical Pearls and Pitfalls**

| Pearls | Pitfalls |
|--------|----------|
| Free all adhesions from both the gracilis and semitendinosus prior to harvest | Premature amputation of either tendon, particularly the semitendinosus, as it needs maximum length to be tripled |
| Take care to harvest the full length of both tendons, particularly the semitendinosus | Uneven tensioning of the 3 limbs of the semitendinosus |
| Even out the limbs of the tripled semitendinosus to ensure each limb is tensioned appropriately | Not accounting for the additional girth of the fibrin clot and circumferential suture |

| Place a circumferential suture around the femoral and intra-articular portions of the graft to contain the fibrin clot. | |

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