Anatomic Anterior Cruciate Ligament Reconstruction with Quadriceps Tendon Autograft

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KEYWORDS

• Anterior cruciate ligament • Quadriceps tendon • Autograft • Harvest

KEY POINTS

- Preoperative measurement of tendon dimensions on magnetic resonance imaging is helpful.
- Measure scalpel depth to approximate depth of incision.
- Begin with medial incision, which has less risk of violating the suprapatellar pouch.
- Avoid cutting bone block more than 10 × 15 mm to minimize risk of fracture.
- Avoiding violation of the suprapatellar pouch can minimize fluid extravasation.
- Incision 1 cm proximal to the superior pole of the patella to 5 cm in length proximally.
- Skin flaps allow visualization through a smaller incision.
- Slight flexion assists with stabilization of the patella during bone cuts.
- A natural plane between the rectus femoris and vastus intermedius allows for harvesting single-bundle or double-bundle grafts).
- May harvest soft tissue graft alone.
- Autologous bone graft (from drill tunnels) into patella harvest defect is recommended.

INTRODUCTION

Reconstruction of the ruptured anterior cruciate ligament (ACL) requires selection of a graft that best accommodates the patient's individual needs. Numerous grafts, including allograft and autograft options, have been described. These options include grafts consisting of soft tissue alone and grafts allowing for osseous healing. Research

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surrounding ACL reconstruction has led to a further understanding of the native anatomy of the ACL. The function of the anteromedial (AM) and posterolateral (PL) bundles of the ACL have led to a better understanding of not only the translational but also the rotational stability provided by the native ACL. As a result, ACL reconstruction may be better approached with a versatile graft that can reproduce the stability provided by the native ACL and allow for graft incorporation and healing. The quadriceps tendon autograft is a versatile option, which takes advantage of osseous healing and allows for both single-bundle and double-bundle reconstruction.

Blauth[1] first described use of the quadriceps tendon for ACL reconstruction in 1984. The original description of this technique describes a double-bundle reconstruction, by which the central third quadriceps tendon is harvested with a bone block from the superior pole of the patella. The bone block was then fixed within the tibia; 1 bundle was fixed to the medial wall of the lateral femoral condyle and the other bundle of the quadriceps tendon was fixed in the over-the-top position. Staubli and colleagues[2] elaborated on this technique, including fluoroscopic evaluation and the development of a press fit, outside in modification. This technique was further popularized because studies reported biomechanical advantages and good clinical outcomes comparing the patellar tendon and quadriceps tendon grafts.[2–4] Harvesting quadriceps tendon grafts showed promise, with less apparent anterior knee pain when compared with patellar tendon grafts.[5,6] Still, a risk of patellar fracture exists not only during harvest but as a result of the defect within the patella postoperatively.[6] Fulkerson and Langeland[7] later described harvesting of the central third quadriceps tendon as a free-tendon graft, thereby reducing the morbidity of harvest regarding anterior knee pain and patellar fracture.[5] The effect of patellar tendon and quadriceps tendon graft harvest on extensor mechanism strength has not been clearly answered, because some studies show an apparent benefit for quadriceps tendon harvest, whereas others show no difference.[8,9]

ANATOMY AND BIOMECHANICS

Anatomy and Biomechanics of the Native ACL

The ACL acts as a primary restraint to anterior translation and tibial rotation. Recent research has led to a more profound understanding of the native ACL. The AM and PL bundles of the ACL provide differential tensioning as the ACL moves through a normal range of motion, with the AM bundle resisting translation and the PL bundle resisting rotation.

The ACL originates on the medial wall of the lateral femoral condyle. Osseous landmarks have been described to improve anatomic ACL reconstruction.[10] The lateral intercondylar ridge identifies the anterior border of the ACL, whereas the bifurcate ridge marks the junction of the AM and PL bundles. The AM and PL bundles are named for their relative insertion on the tibia. Anatomic landmarks used to locate the tibial insertion of the ACL include the intercondylar eminence, anterior horn of the lateral meniscus, and the posterior cruciate ligament. The insertion of the ACL is variable, especially with regartd to the orientation of the AM and PL bundles. As a result, preserving the ACL remnant can aid in determining tunnel position, and may be even more important when a double-bundle reconstruction is planned.[11]

Anatomy and Biomechanics of the Quadriceps Tendon

The quadriceps tendon is formed by the tendinous insertion of the anterior thigh musculature, with the central third primarily consisting of a confluence of the rectus femoris and vastus intermedius. The resultant insertion maintains this relationship by maintaining a natural plane within the tendon. This division within the tendon can be useful, especially in double-bundle ACL reconstructions. The quadriceps tendon inserts directly onto the anterior half of the patella in an oblique orientation.[3] The quadriceps tendon has an average thickness of 8 mm, which is nearly twice the thickness of the patellar tendon and more closely replicates the dimensions of the native ACL. Furthermore, the quadriceps tendon has shown similar biomechanic properties, capable of exceeding those of the intact ACL (**Table 1**).[4,12]

FIXATION OPTIONS

The method of fixation for quadriceps tendon graft can vary based on surgeon preference. The presence of osseous and soft tissue components allows for a variety of options. Interference screw fixation can be used on both osseous and soft tissue components. Suspensory fixation for a bone plug within the femoral tunnel has been successfully used, including the ENDOBUTTON (Smith and Nephew, Andover, MA). On the tibial side, suspensory fixation may be used alone, or to reinforce interference screw fixation. In cases of a short graft, suspensory fixation such as tying over a post may be advantageous. All inside systems with unique fixation have been described as well.

The versatility of the quadriceps tendon for methods of fixation makes it desirable for revision cases as well. If a bone block is used, it can be secured within the defect. In addition, with the increased cross-sectional area of the quadriceps tendon, apposition can be achieved circumferentially within the tunnel.

The quadriceps tendon can be used for over-the-top ACL reconstructions as well. If a bone block is used in these cases, it is secured within the tibial tunnel. The tendinous portion can be secured proximally over a post. It is critical to be sure that adequate graft is harvested when over-the-top reconstructions are performed.

SURGICAL TECHNIQUE: HARVEST

The patient is positioned supine on the operating room table. The central quadriceps tendon can be harvested using a leg-holder with the end of the bed flexed or with the foot on the table and a post for lateral support. When using a post, 2.26-kg and 4.53-kg (5-pound and 10-pound) sand bags can be used for the foot to rest at variable knee flexion angles during graft harvest. Doing so allows for varied exposure of the quadriceps tendon and patella through the incision.

The incision is made longitudinal at the proximal pole of the patella, following the central axis of the quadriceps tendon 5 cm proximal (**Fig. 1**). During exposure, care is taken to maintain meticulous hemostasis. Skin flaps are developed to allow for adequate visualization of the quadriceps tendon origin proximally, the patella distally,

Table 1
Biomechanical characteristics of selected grafts. Comparison of quadriceps tendon, patellar tendon, and quadrupled hamstring with the native ACL

Graft	Tensile Load (N)	Stiffness (N/mm)	Cross-Sectional Area (mm^2)
Quadriceps tendon[4,12]	2352	463	62
Patellar tendon[13]	2977	620	35
Quadruple hamstring[14]	4090	776	53
Native ACL[15]	2160	242	44

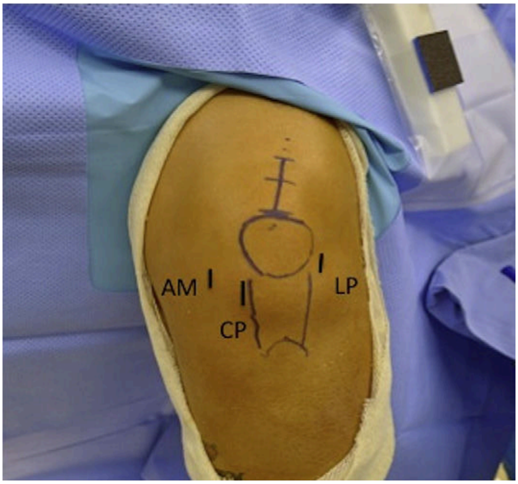

Fig. 1. Incision and portals for quadriceps tendon harvest. A longitudinal incision is planned in line with the fibers of the quadriceps tendon to a point 3 to 5 cm proximal to the patella. A far lateral portal (LP) is placed above the patellar fat pad, whereas a central portal (CP) and an accessory medial portal (AM) are placed medially.

and the medial and lateral aspects of the quadriceps tendon and patella. The central fibers of the quadriceps tendon are followed to a point 6 to 7 cm proximal to the superior edge of the patella. A 10-mm-wide tendon segment is incised using a number 10 blade, taking care to avoid violating the suprapatellar pouch. A Kelly clamp can be passed under the distalmost quadriceps tendon to develop the plane between the quadriceps tendon and suprapatellar pouch.

The patellar cuts are planned next, extending the 10-mm-wide segment distally to a point 15 mm distal from the superior pole of the patella. Needle-tip electrocautery is used to extend the incisions and remove any intervening soft tissue for saw cuts. Using a small oscillating saw, longitudinal bone cuts are made to a depth of 8 to 10 mm, angled 20° to 40° toward midline, creating a trapezoid bone plug. The final transverse bone cut is made after confirming the length of the bone plug. Care must be taken to avoid creation of stress risers. A curved 0.6-cm (0.25-inch) osteotome is used to complete the cuts and free the bone plug.

Another option to avoid creating a patellar stress riser is to perform an undercut on the patellar bone plug. The same angled cuts are created, and the soft tissue graft is released proximally and extended distally. The tendon insertion is well visualized on the proximal patella, then a small sagittal saw is used to make an undercut at the insertion, creating a true trapezoidal bone plug.

The soft tissue component of the graft is then released at least 7 cm from the superior pole of the patella to ensure an adequate soft tissue component to the graft. The graft is then taken to the back table for preparation (**Fig. 2**). Any defect made in the suprapatellar pouch is closed before arthroscopy to avoid extravasation of fluid and potential complications therein. The tendon defect is reapproximated and a standard closure with nonbraided suture is performed. The patellar defect can be bone grafted using bone chips from the graft preparation or from the bone debris from tunnel drilling. Alternatively, a core reamer can be used on the tibial side and that bone can be grafted into the patellar defect.

Fig. 2. Quadriceps tendon autograft. Harvested quadriceps tendon harvest with superior pole patella bone block.

Alternatively, a graft consisting of soft tissue alone may be harvested. In this case, careful attention must be paid to the proximal extent of the graft and harvesting a tendon of adequate length. If an adequate length graft can be harvested, the central 10-mm segment is longitudinally incised. Depending on the thickness of the tendon and surgeon preference, the harvest can incorporate the entire rectus femoris and a partial-thickness vastus intermedius tendon (leaving some on the synovial layer), or a full-thickness graft may be obtained by taking the entire vastus intermedius through the synovial layer. After releasing the distal attachment to the superior pole of the patella, the graft is released proximally, as described earlier.

The graft harvest can be modified to a more cosmetic horizontal incision at the superior pole of the patella. Skin flaps are mobilized to expose the superior pole of the patella and quadriceps tendon. A bone plug may be harvested as above. Special tools such as a double-bladed scalpel can aid in proximal tendon harvest with minimal exposure, however care must be taken to avoid violating the nearby musculature. Finally, an accessory incision is made proximally for release of the tendinous portion.

SURGICAL TECHNIQUE OF ACL RECONSTRUCTION

Portals

The basic principles of anatomic ACL reconstruction are followed when quadriceps tendon autograft is used. As discussed earlier, both single-bundle and double-bundle ACL reconstruction can be performed. Standard arthroscopy portals are created, including lateral, central, and accessory medial portals (see **Fig. 1**). By using a central and accessory medial portal, adequate visualization of the native origin from the lateral femoral condyle can be appreciated and a safe tunnel trajectory maintained (**Fig. 3**).

Arthroscopic Evaluation

During diagnostic arthroscopy, evaluation of the ACL remnant and notch dimensions allows for decision making of the optimal method of reconstruction. Measurements of ACL insertion length as well as bundle width for both the femoral and tibial insertions are obtained (**Fig. 4**). Measurements of both notch width and height are obtained as well. Generally, for patients with a tibial insertion of less than 14 mm, a single-bundle reconstruction is recommended, whereas with lengths of more than 18 mm, a double-bundle reconstruction is recommended. In addition, for those patients with a notch width less than 12 mm, a single-bundle reconstruction is recommended.

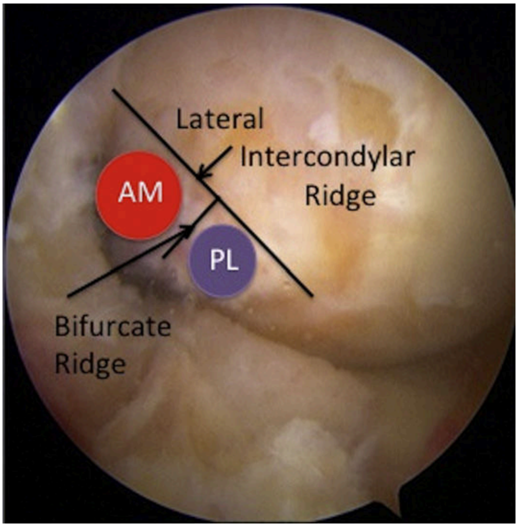

Fig. 3. The native ACL origin from the lateral femoral condyle as viewed from the central portal. Adequate visualization allows for identification of osseous landmarks, including the lateral intercondylar ridge and the bifurcate ridge. These landmarks assist in identification of the native AM and PL bundles.

Femoral Tunnel Preparation

When performing ACL reconstructions with the quadriceps tendon, a single femoral tunnel is used regardless of whether a single-bundle or double-bundle reconstruction is planned. First, the native AM and PL bundles are identified (see **Fig. 3**). Next, the single femoral tunnel is placed at a midpoint between the centers of the femoral AM

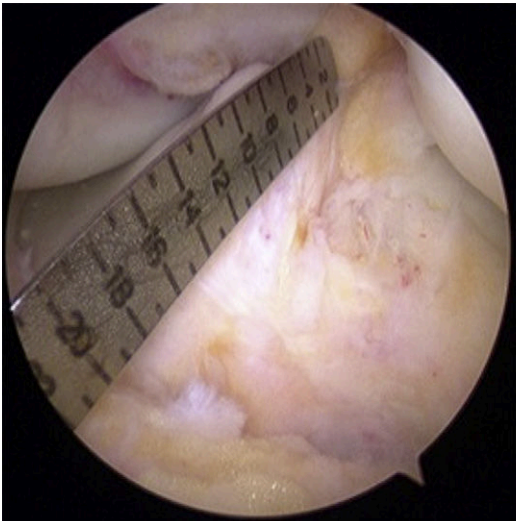

Fig. 4. Measurement of the native ACL insertion onto the tibia, as viewed from the lateral portal. Careful evaluation of the native ACL anatomy assists in surgical planning for the optimal technique to reproduce the native ACL anatomy.

and PL insertion. An awl is used to mark the desired entry point for a guide pin, with the knee hyperflexed. The distance to the lateral femoral cortex is determined, and the tunnel is expanded to accommodate the graft.

Tibial Tunnel Preparation

Preparation of the tibial tunnels is performed after defining the anatomic centers of the tibial AM and PL attachments. The native anatomy of the tibial insertion is identified before planning guide pin and tunnel placement. The centers of the AM and PL bundles are identified. Before guide pin passage, a longitudinal incision is performed at the desired location over the proximal tibia.

For cases in which a double-bundle reconstruction is planned, 2 tibial tunnels are created, taking care to avoid tunnel convergence and maintain the native anatomic orientation. Assessment of pin spread is performed before tunnel preparation with traditional guide pin placement. Another option for surgeons is to use a RetroDrill (Arthrex, Naples, FL) system to prevent tunnel convergence, because the 2 tunnels can be drilled simultaneously. For preparation of the PL tunnel, the tibial guide is set at 45°, centered within the PL remnant, and positioned over the AM tibia at the juncture of the posterior one-third and anterior two-thirds. Next, the guide is adjusted to 55°, centered within the AM insertion, and positioned at the juncture of the anterior one-third and posterior two-thirds over the medial aspect of the tibia. It is important to be mindful of tunnel positioning as the obliquity of these tunnels may result in convergence on the articular side.

For some patients, a single-bundle reconstruction best reproduces the native anatomy. If a single-bundle reconstruction is planned, a central point midway between the tibial AM and PL anatomic centers is cleared of soft tissue. A guide set at 55°, centered between the AM and PL bundles is used to pass a guide pin drilled in a retrograde fashion from the proximal tibia. A traditional tibial guide or a RetroDrill can be used to create the tibial tunnel.

Graft Passage and Fixation

Graft passage is performed maintaining the orientation of the graft to reproduce the orientation of AM and PL bundles whether 1 or 2 tibial tunnels are created. First, the bone block is passed from the accessory medial portal into the femoral tunnel, maintaining the AM and PL bundles in their anatomic orientation. If a single-bundle reconstruction is performed, the sutures of the graft are pulled into the tibial tunnel, and the graft is passed in an antegrade fashion. The graft is then fixed in 15° to 20° of flexion. When a double-bundle reconstruction is performed, the PL bundle is passed before the AM bundle. The PL bundle is secured in full extension while the AM bundle is secured in 45 degrees of flexion.

OUTCOMES/COMPLICATIONS

The outcomes of ACL reconstruction have focused primarily on hamstring, patellar tendon, and allograft options. Increasing evidence is showing the benefits of the quadriceps tendon graft as well as recognizing inherent risks in the graft harvest.

ACL reconstruction with the central third quadriceps tendon has shown excellent stability in follow-up.[6] Good outcomes have been shown in follow-up of not only primary but also revision surgery when quadriceps autograft has been used.[16–18] Hamstring and allograft tissue has raised concern of long-term graft stability and maintenance of graft integrity, which has not been shown in cases undergoing quadriceps tendon autograft.

Quadriceps tendon harvest does not seem to be as detrimental to the extensor mechanism as patellar tendon harvest. Several studies have found quadriceps harvest

Table 2
Complications of selected grafts for ACL reconstruction. Incidence of anterior knee pain and patellar fracture as well as the resultant weakness after quadriceps tendon, patellar tendon, and hamstring tendon after graft harvest

Graft	Anterior Knee Pain (%)	Weakness (% Loss)	Patellar Fracture (%)
Quadriceps tendon	5[21]	11[6]	1.2[6]
Patellar tendon	17–26[21,22]	10–18[23]	0.2–1.8[24,25]
Hamstring	11[22]	10[23]	Not applicable

to result in less of a decrease in extensor mechanism strength than patellar tendon harvest.[8,19] Lee and colleagues[6] also found excellent stability with quadriceps tendon grafts and muscle recovery of 80% to 82% at 1 year and 89% at 2 years after surgery.[20]

Anterior knee pain is a well-recognized sequela of patellar tendon harvest. Recent studies comparing quadriceps tendon with patellar tendon have shown less anterior knee pain.[21] In addition, these patients have not shown the patellar tendon shortening and infrapatellar contracture associated with patellar tendon autograft.[21]

Complications related specifically to graft harvest include weakness, patella fracture, donor site-related pain as well as cosmetic consequences of an additional incision proximal to the patella (**Table 2**). The quadriceps tendon is a hypervascular region with an inherent risk of bleeding and careful attention should be paid to hemostasis. As outlined earlier, the insult to the extensor mechanism and incidence of anterior knee pain does seem to be lessened in patients undergoing quadriceps tendon harvest. The risk of fracture seems to be similar for patellar tendon and quadriceps tendon grafts, with an incidence of 0.2% to 2.0% for patellar tendon and 1.2% for quadriceps tendon.[6,24,25]

SUMMARY

The quadriceps tendon is an excellent option for autograft ACL reconstruction, with structural properties approximating those of more traditional grafts. As we understand more about the native anatomy of the ACL and how to best restore that anatomy, the graft options must advance as well as the methods of fixation to allow for reliable incorporation and healing of the graft after surgical reconstruction. The quadriceps tendon shows promise as a graft for ACL reconstruction because its anatomic and biomechanical characteristics closely approximate the native ACL. Also, the quadriceps tendon can be used to perform both single-bundle and double-bundle reconstruction and shows tremendous potential for revision cases. The versatility of this graft may prove to be more beneficial as understanding of the restoration of knee kinematics after ACL reconstruction improves. Long-term clinical outcome studies will help to assess the relative advantages and disadvantages of grafts used for ACL reconstruction. The goal of anatomic ACL reconstruction using quadriceps tendon autograft is an individualized, functional ACL reconstruction that allows for safe return to full activity.

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