Review Article

Evolution in ACL Autograft Harvesting Techniques: Transition to Minimally Invasive Autograft Harvesting

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ASSOCIATED VIDEO

ABSTRACT

Surgical techniques for anterior cruciate ligament (ACL) reconstruction continue to evolve. Harvesting techniques for commonly used ACL autografts such as bone patellar tendon bone, hamstring, and quadriceps tendon have similarly continued to progress. Traditional larger incisions for graft harvesting that were described in the 1980s have given way to smaller or more minimally invasive techniques. Advantages of these techniques are primarily anatomy based and include the following: decreased nerve complaints such as hypoesthesia or dysesthesia, improved cosmesis, decreased surgical site pain or morbidity, and, in the case of hamstring harvesting, easier tendon identification. The current literature supports reproducible minimally invasive or modified graft harvesting techniques for bone patellar tendon bone, hamstring, and quadriceps tendon autografts. Specialized instrumentation is available to simplify the harvesting process. Each of these techniques is described in detail outlining surgical steps, technical considerations, and precautions. Knowledge and review of these techniques provides the surgeon with greater flexibility and options when choosing and harvesting autograft tissue for ACL reconstruction.

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The treatment of anterior cruciate ligament (ACL) injuries has continued to progress. Initial conservative treatment in the 1970s and early 1980s has given way to surgical management.[1] A notable amount of time and research has gone into nearly every aspect of the surgical management for ACL reconstruction.[2] The transition from open repair or reconstruction to two-incision reconstruction was then followed by endoscopic transtibial ACL reconstruction, with the most recent trend being anatomic reconstruction that involves independent placement and drilling of the femoral and tibial tunnels.[3-5] Similarly, notable debate in the literature has occurred over the merits of single-bundle versus double-bundle ACL reconstructions.[6] Various other aspects of the reconstruction including tunnel placement and graft fixation have also received notable attention in the literature.

Table 1. Surgical Tips and Risks or Precautions

Methods	Tips	Risks or Precautions
Two-incision BPTB	• Consider vertical vs transverse incisions	• Careful attention to surface anatomy
	• Tibial incision midline[15,16] vs medial to tibial tubercle[17]	• Same care in patellar bone plug harvest as one-incision technique to prevent harvest site fracture
	• Familiarity with patellar tendon stripper or blade	—
	• Pass subcutaneously between the two incisions	—
Posterior mini-incision hamstring	• Use a prepping and draping technique that allows the tourniquet to be placed proximal and the leg to be placed into 30° flexion and external rotation[17] for the more proximal and posterior incision	• Incision closer to popliteal neurovascular structures
	• Blunt dissection and hook the tendon with either a right angle or finger[17]	• Incision in flexion crease might increase wound healing issues
	• Requires both open- and closed-ended hamstring tendon strippers if a free tendon graft is desired	If using for ACLR and not performing an all-inside ACLR requires an added incision
QT	• Careful attention to clearing off the soft tissue overlying the QT	• Risk of hematoma secondary to injury to the descending branch of the lateral femoral cutaneous artery—be careful not to stray lateral and use arthroscopic electrocautery devices to ensure hemostasis
	• Specialized graft harvesting instrumentation required—important to be familiar with the instruments to prevent inadvertent premature graft truncation	• Risk of inadvertent capsular penetration into the suprapatellar pouch if quadriceps dissection is too deep
	—	• Popeye muscle deformity secondary to harvesting too far proximal
	—	• Risk of superior patella fracture during harvesting

ACLR = anterior cruciate ligament reconstruction, BPTB = bone patellar tendon bone, QT = quadriceps tendon

Surgical reconstruction of the ACL include the following steps: examination under anesthesia, diagnostic arthroscopy, graft selection, graft harvesting, femoral and tibial tunnel positioning or drilling, graft passage, graft fixation, and rehabilitation. The merits of allograft versus autograft ACL reconstruction have received a notable amount of attention in the orthopaedic sports medicine literature.[7,8] Commonly used autografts include bone patellar tendon bone (BPTB), hamstring, and quadriceps tendon (QT).[9,10] As with steps such as tunnel placement and graft fixation, techniques associated with ACL autograft harvesting have evolved. This progression has been from traditional larger incisions for graft harvesting toward smaller or more minimally invasive techniques. Reproducible mini-incision or minimally invasive techniques are now available for harvesting BPTB,[11-14] hamstring,[15-20] and QT[21-26] autografts.

Potential Benefits of Minimally Invasive, Mini-Incision, or Modified Graft Harvesting Techniques

As with all surgical modifications (Table 1), the goals of these techniques are to improve the patient's satisfaction and outcomes while using techniques that provide for reproducible autograft tissues (Figure 1). Goals often cited in the literature for these modified techniques are graft specific. For example, two-incision BPTB harvesting has been shown to diminish nerve complaints such as hypoesthesia or dysesthesia and improved ability to kneel.[11,12] As it relates to posterior mini-incision hamstring harvesting techniques, published advantages include easier hamstring tendon identification, harvesting, and decreased risk of inadvertent partial graft harvesting or early graft truncation.[15-18] Minimally invasive QT harvesting techniques have been touted to diminish surgical trauma and decrease post-operative pain.[21,25] Finally, cosmetic advantages exist with many of these techniques.[11,12,17,18,21,25]

Minimally invasive graft harvesting techniques provide an alternative to traditional harvesting procedures, but strict attention to detail must be maintained to prevent complications (Table 1). As with all surgical procedures, potential complications can occur. Recognized complications associated with traditional ACL autograft harvesting such as patella fracture, inadvertent graft truncation, extensor mechanism injury, wound dehiscence, and infection can occur. The same complications apply to minimally invasive graft harvesting techniques. Minimally invasive harvesting techniques can carry increased risks associated with limit exposure, such as inadvertent graft truncation (BPTB and QT grafts). It should also be noted that posterior mini-incision hamstring harvesting places the incision closer to the popliteal neurovascular bundle within the flexion crease. As such, attention to surgical dissection is important. As with all procedures, it is critically important that the surgeon familiarize themselves with the relevant anatomy, the specialized instrumentation used for the procedures, and published techniques before transitioning to minimally invasive harvesting.

Figure 1

Photograph of specialized graft harvesting instrumentation. Top left: Parasmillie patellar tendon stripper or blade (ConMed) for two-incision bone patellar tendon bone (BPTB) harvesting; top right: minimally invasive QT instruments (Karl Storz)—tendon blade, tendon separator, and open-ended tendon cutter; bottom center: modular calibrated graft knife handle and closed-ended QT stripper or cutter (Arthrex) (Video 2)

It should be noted that numerous different techniques are available to perform minimally invasive graft harvesting. The goal of this manuscript is to outline several of the more commonly cited examples in the literature for illustrative purposes. For a more detailed explanation of each individual technique, refer to the authors' original articles that are referenced. In addition, many of the authors have produced excellent video explanations of their techniques, and viewing these videos is also highly recommended.

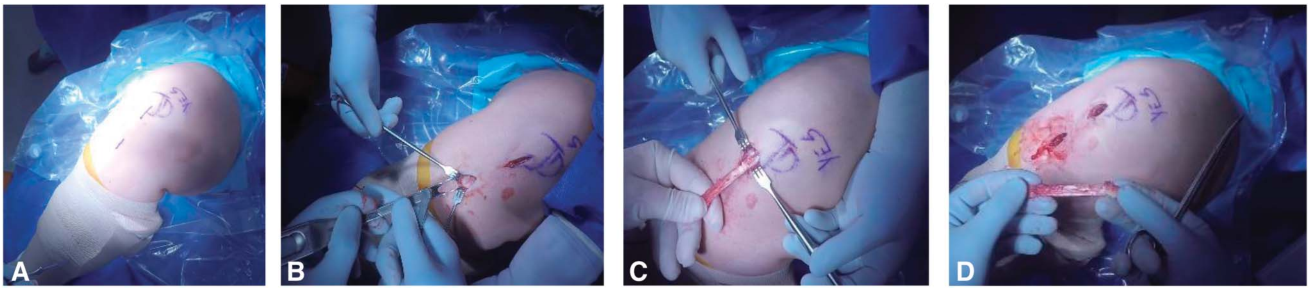
Two-Incision Bone Patellar Tendon Bone Techniques

Anatomy plays a prominent role in several of the advantages associated with the rationale for using a minimally invasive BPTB harvesting technique. One of the key relevant anatomic advantages of this technique centers around the anatomy of the saphenous nerve. Studies have indicated that two or three branches of the infrapatellar portion of the saphenous nerve are at risk of injury during traditional BPTB harvesting.[11] When a traditional, standard one-incision bone patella bone graft harvest is performed, these nerves are severed causing patients to experience hypoesthesia or dysesthesia along the anterolateral aspect of the knee and proximal tibia. A two-incision graft harvesting approach allows for preservation of these sensory nerves.

Two-Incision Bone Patellar Tendon Bone Harvesting

Traditional BPTB harvesting techniques for ACL autograft described an incision from the inferior pole of the patella to the tibial tubercle either centered at midline or just medial to midline.[27,28] As previously mentioned, this incision does require disruption of the infrapatellar portion of the saphenous nerve with associated sensory involvement. Various two-incision minimally invasive BPTB harvesting techniques have been described throughout the literature.[11-14,29,30] Most techniques described an upper incision made overlying the inferior pole of the patella and a lower incision centered on the tibial tubercle. However, some authors have described the lower incision as being placed 1 to 2 cm medial to the tibial tubercle to assist in the tibial tunnel drilling.[17] Similarly, the two incisions are typically described as being vertically placed, but some authors have recommended transverse or horizontal incisions.[19,40] The

Figure 2



Technique for two-incision minimally invasive bone patellar tendon bone (BPTB) harvesting: (**A**) photograph of the knee with the proposed incisions, (**B**) photograph of the two-incision harvest technique with double-bladed Parasmillie Blade beginning at patellar tendon harvest site distally at level of tibial tubercle, (**C**) photograph exposing graft after harvested tibial bone plug and patellar tendon shuttled to proximal incision, and(**D**) photograph of harvested BPTB graft.

advantage of the vertical incision is that it can be readily converted to a traditional graft harvesting approach or incision if necessary. The potential advantage for the transverse incisions is that they are made in Langer lines and as such have cosmetic benefits.

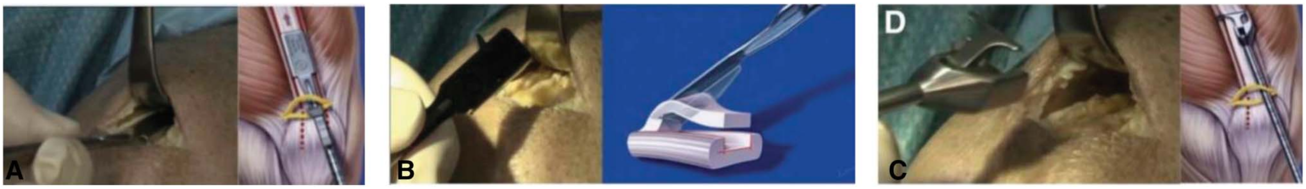
Two-Incision Surgical Technique

The knee is positioned at 90° of flexion[11-13,29,30] (Figure 2). The inferior pole of the patella, medial and lateral edges of the patellar tendon, and the tibial tubercle are palpated and marked. The locations for the two incisions are then drawn. The proximal incision is begun at the distal aspect or inferior pole of the patella and extending 2 to 2.5 cm proximal. The distal incision is centered over the tibial tubercle. Dissection is carried through the subcutaneous tissues. Scissors are used to pass subcutaneously from the proximal to the distal incision between the peritenon and anterior aspect of the patellar tendon. Graft harvesting can be performed using a double-bladed graft stripper (Parasmillie Blade; ConMed) from distal to proximal, or several authors have referenced using an Ethibond suture from proximal to distal as a Gigli saw through the tendon[11] or a meniscotome or Smillie knife.[29] If the Parasmillie Blade (Figure 1, A) is used, then attention is turned first to the tibial tubercle bone plug because the graft is harvested from distal to proximal. The medial and lateral edges of the patellar tendon are visualized, and the proposed location for the tibial bone plug can be marked with electrocautery or a scalpel. Once this has been outlined, an oscillating saw is used to make the resections along the medial, lateral, and distal edges. The bone plug is left intact on the tibia, and attention is turned to harvesting the patellar tendon with the double-bladed tendon stripper. The Parasmillie Blade is advanced from the tibial bone plug proximally with retractors being moved from the distal incision to the proximal incision. The double-bladed tendon stripper is advanced until the edges contact the inferior pole of the patella. At this point, electrocautery or a scalpel is then used to outline the patellar bone plug. An oscillating saw is used to make the bone cuts. Attention is turned back to the tibial bone plug that is now elevated from the tibial tubercle using an osteotome. A surgical clamp is used to shuttle the graft between the two incisions. This brings the bone plug and the harvested patellar tendon into the proximal wound. Finally, an osteotome is used to remove the patellar bone plug. Grafting of the patellar defect and closure of the patellar tendon defect might be performed as per the surgeon's preference (Video 1).

Figure 3

Posterior mini-incision hamstring harvesting: (**A**) photograph of patient positioning and location of incision, (**B**) photograph of the semitendinosus and gracilis localized through the incision, and (**C**) photograph of open-ended tendon stripper harvesting the semitendinosus proximally (photographs from the work of Khanna et al[15]).

Figure 4



Minimally invasive quadriceps tendon (QT) with bone plug harvesting (Fink technique): (**A**) photograph with double-bladed tendon blade harvesting QT, (**B**) photograph of tendon separator creating the thickness for the graft, (**C**) photograph of the open-ended QT cutter (photographs from the work of Fink et al[23]).

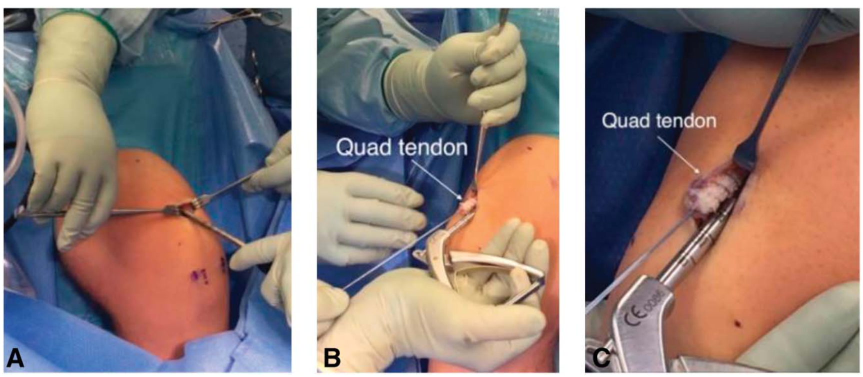
Posterior Mini-Incision Hamstring Harvesting

As with the two-incision BPTB technique, potential advantages of the posterior hamstring harvest technique are based primarily on anatomic benefits. One of the difficulties encountered with traditional harvesting techniques along the anteromedial tibia is identifying the semitendinosus and gracilis tendons because they are deep to the sartorial fascia. The traditional anterior harvest incision is made midway between the tibial tubercle and the posterior medial border of the tibia at the level of the tibial tubercle overlying the pes anserine region.[31,32] The incision is typically 2 to 3 cm in length.[31,32] Pertinent musculoskeletal anatomy and sensory nerve anatomy regarding the harvest site include the fact that both the infrapatellar and sartorial branches of the saphenous nerve are at risk of injury. Once the incision is carried through the subcutaneous tissues, the sartorial fascia is bluntly dissected to avoid injury to both the saphenous nerve and medial collateral ligament.[31] The borders of the gracilis, which is more proximal, and the semitendinosus tendons are palpated. The sartorial fascia is incised. Dissection to isolate both the gracilis and semitendinosus tendons is then performed.[31] A potential advantage of the posterior hamstring harvest is that the incision is placed more proximal to this in the region where the tendons are readily palpable, thus allowing for easier tendon identification. Another difficulty frequently highlighted in the literature with hamstring autograft harvesting is that the fascial bands attached to the tendons if not visualized and dissected free can lead to premature transection of the tendon and result in a graft of either inferior quality or inadequate length.[33] By placing the posterior incision more proximal, these fascial bands are directly visible and can be more easily dissected free before graft harvesting, preventing premature transection. Finally, the traditional anteromedial harvest site places the infrapatellar and sartorial branches of the saphenous nerve at risk. As such, they are more likely to be injured iatrogenically when using this traditional approach, leading to sensory nerve complaints.

Posterior hamstring surgical technique

Various surgical techniques have been reported for the posterior mini-incision technique[15-20,34,35] (Figure 3). Prepping and draping of the leg is a crucial step to ensure that abduction and external rotation of the leg allows

Figure 5



Minimally invasive quadriceps tendon (QT) all soft-tissue graft harvesting (Saper): (**A**) photograph of incision with calibrated knife handle and double-bladed knife (**B**) photograph of distal soft-tissue graft whipstitched, and the closed-ended tendon stripper or cutter (Arthrex) advanced along graft to truncate graft proximally (**C**) photograph of all soft-tissue QT graft before proximal truncation (photographs from the works of Saper[21]).

exposure to the posterior medial aspect of the knee and that the tourniquet has been placed proximal enough. The knee is flexed 30 degrees and externally rotated.[18] A 2- to 3-cm transverse incision is made overlying the palpable medial hamstring tendons at roughly the level of the popliteal crease. Specifically, the incision is made in the center of the medial half of the popliteal fossa in the area of soft, sunken creaseless skin.[18] The fascia overlying the tendons is released. At this level, the more medial tendon is the gracilis, and the more lateral tendon is the semitendinosus.[15] This more proximally placed incision allows for direct visualization of the accessory soft-tissue connections that are particularly common with the semitendinosus and attach to the medial gastrocnemius. These fascial bands are responsible for the unintended failure to strip the tendon up to the muscle-tendon junction that can occur with the traditional anterior hamstring harvest technique. The proximal end of the tendon is then harvested using an open-ended tendon stripper. Once this has been performed, if desired, the distal attachment along the proximal medial tibia can then be harvested or transected using a closed-ended tendon stripper. When necessary, the gracilis tendon can then be harvested in a similar manner. Because of the more proximal and posterior position of the incision, improved cosmetics have been mentioned by multiple authors as an advantage to this technique. For surgeons performing ulnar collateral ligament reconstruction (UCLR) and all-inside anterior cruciate ligament reconstruction (ACLR) using hamstring autografts, this harvesting technique might also be beneficial. The senior author has extensive experience with UCLR and uses the posterior mini-incision harvesting technique when a hamstring graft is used for the reconstruction. It should be noted that for traditional ACLR, this technique requires an additional incision and provides no cosmetic benefits. However, for surgeons performing all-inside ACLR using second-generation retrograde drilling and tensioning devices, as described by Lubowitz et al,[34] these benefits can be obtained.

Minimally Invasive Quadriceps Tendon Harvesting

In recent years, the use of a central QT autograft for ACL reconstruction has received more attention. Advantages associated with QT autografts include decreased anterior knee pain,[21] decreased pain associated with kneeling, no iatrogenic injury to the infrapatellar branch of the saphenous nerve, and a graft load to failure characteristics that are similar to the native ACL.[36] Pertinent graft anatomy regarding the QT includes the following: typical length 7 to 8.5 cm, typical width 2.5 to 3 cm, and typical thickness 16 to 18 mm; useable length is from the superior pole of the patella to the myotendinous junction of the rectus femoris, and the greatest thickness of the QT is distally at the insertion.[9,37-39] The anatomy of the suprapatellar pouch is also important to understand in relationship to the QT. The suprapatellar pouch might extend up to 5 cm proximal to the superior pole of the patella.[22] Finally, recognizing the relevant vascular anatomy surrounding the harvest site, including the descending branch of the lateral circumflex femoral artery that runs distally between the vastus lateralis and rectus femoris, is important.[22] Provided that graft harvesting does not drift laterally and a central QT graft is obtained, the artery should not be injured.[22]

Technique Summary

Either a transverse or vertical incision approximately 1.5 to 2 cm in length is made at, or just lateral to, the midline.[21,23-26] Once the incision is made, the subcutaneous tissues are dissected free from the superficial surface of the QT for a distance of approximately 7 to 8 cm. The arthroscope might be used to confirm that the soft tissue has been dissected free and to inspect the direction that the QT is running.[21] Arthroscopic electrocautery devices can be used if necessary to prevent postoperative hematoma. Specialized QT harvesting equipment is available, including double-bladed graft knives, tendon separators, and both open-ended and close-ended QT cutters (Figure 1, B and C). The QT can be harvested as a soft-tissue graft without a bone plug, or an oscillating saw can be used to harvest a bone plug from the proximal patella.

Minimally Invasive Quadriceps Tendon With the Bone Plug Harvesting Technique

In the technique described by Fink et al,[24] a transverse skin incision approximately 2 to 3 cm in length is made over the superior border of the patella[23,24] (Figure 4). The bursal layers are then dissected to expose the QT, and a retractor is used to obtain more proximal exposure. Specialized instrumentation (Karl Storz) for graft harvesting is used (Figure 1, B). A tendon knife with two parallel blades is advanced to the 6-cm mark, as measured from the superior pole of the patella. Graft widths measuring from 9 to 12 mm can reproducibly be obtained. The thickness of the graft is defined with a tendon separator, which is set at a depth of 5 mm and is advanced to the 6-cm mark. The graft is then cut with an open-ended QT cutter after being advanced to the desired length of typically 6 cm (if a graft is obtained without a bone plug, the tendon length is typically harvested to 7 cm). The graft is then reflected distally, and a whipstitch is placed in the free end of the graft. If a QT autograft with bone plug is desired, then a scalpel is used to outline the area for patellar harvest, and this is followed by an oscillating saw. To avoid a patellar fracture, it is advisable to finish the sawing parallel to the anterior patellar surface in a proximal to distal direction with a narrow saw blade.[23,24] The patellar thickness should not exceed 30%, as recommended, and the bone plug should not be harvested from the lateral aspect of the patella so as to decrease the risk of iatrogenic patellar fracture.[22]

Minimally Invasive Quadriceps Tendon Soft-Tissue–Only Graft Harvesting Technique

In the technique described by Slone et al, the leg is flexed to 90°, the surface anatomy surrounding the proximal patella is palpated and marked out, and a 1.5- to 2-cm vertical mark is made extending from the superior patella proximally[21,26] (Figure 5). The useable length of the QT is from the superior aspect of the patella to the rectus femoris tendon. It is confirmed at this point that a graft length of at least 6.5 cm can be obtained.[21] Once the soft tissue is elevated off the superficial surface of the QT, an arthroscope with the fluid off can be inserted into the incision to inspect the tendon, determine its length, and mark the skin at the location of the maximal useable length. This step is performed to prevent a graft harvest complication such as inadvertent truncation or obtaining an unexpectedly short graft length. Specialized instrumentation is available to aid in the harvesting process (Figure 1, C). A double-bladed quadriceps harvest knife is used, and the calibrated knife handle is used as a reference for advancing approximately 7 cm superior to the superior pole of the patella. If a soft-tissue–only QT graft is desired, then the graft is transected distally at the level of the superior aspect of the patella. The distal end of the graft is carefully elevated so as to avoid capsular penetration into the suprapatellar pouch. The soft-tissue QT graft is trimmed to the appropriate diameter, the free end whipstitched, and, with traction applied, a close-ended QT stripper or cutter (Arthrex) is then advanced along the graft to the desired length where the graft is truncated proximally.[21] Some authors recommend closing the quadriceps defect along its subcutaneous or anterior surface (fan-like closure).[23] Harvesting past the rectus femoris tendon is not recommended because a Popeye deformity has been described.[40]

Summary

As with all components of the ACL reconstruction, autograft harvesting techniques have continued to evolve. The evolution of these techniques has been based primarily on a desire to address some of the anatomic limitations associated with more traditional harvesting techniques. Currently, there are well-described and reproducible minimally invasive techniques available for harvesting BPTB, hamstring, and QT autografts. A thorough knowledge of the soft-tissue anatomy surrounding the knee, and working familiarity with some of the specialized instrumentation that has been developed in recent years, provides surgeons with greater flexibility and options for harvesting graft material for ACL reconstruction. In addition to improved cosmesis, some of the observed advantages of these techniques include decreased iatrogenic sensory nerve injuries, decreased surgical site morbidity, and improved or more reproducible hamstring tendon harvest.

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