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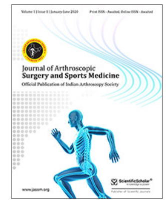

Arthroscopic Techniques

Endoscopic, full-thickness, soft-tissue, quadriceps tendon harvesting

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ABSTRACT

Quadriceps tendon (QT) graft utilization for anterior cruciate ligament reconstruction has gained popularity among surgeons lately, due to the favorable biomechanical characteristics and clinical results. The growing interest in this graft has resulted in the development of minimal invasive harvesting techniques. Nevertheless, QT graft harvesting is considered a technically demanding procedure with a steep learning curve. This technical note describes the endoscopic approach of QT graft harvesting and aims in helping the surgeon to safely harvest the graft and to minimize the complication rate.

Keywords: Anterior cruciate ligament reconstruction, Quadriceps tendon harvesting, Minimally invasive, Endoscopic

INTRODUCTION

The unsatisfactory results of anterior cruciate ligament reconstruction, in terms of return to play[1] and progression to osteoarthritis,[2] have forced the scientific community to seek improved surgical techniques. Graft selection is one of the topics debated, with the quadriceps tendon (QT) graft gaining popularity among anterior cruciate ligament (ACL) surgeons.[3]
QT graft is an attractive option due to its predictable size and great versatility. It can be used as a partial or full thickness graft, with or without bone block and with different widths and lengths, according to the surgeon's preference and the patient's needs.
Moreover, the QT graft has demonstrated favorable biomechanical characteristics[4,5] and equivalent or superior clinical results compared to bone-patella tendon-bone and hamstrings with significantly lower complication rate.[6]
The increased interest in the QT graft resulted in the evolution of harvesting techniques, with many authors describing a minimal invasive approach, aiming in less pain and better cosmesis.[7-11]
Nevertheless, QT graft remains the third option in ACL reconstruction among surgeons.[3] The main reason for this is probably the unfamiliarity of surgeons with the QT graft harvesting. Reported complications of QT graft harvesting are patella fracture, extensor apparatus rupture, hematoma formation, quadriceps strength weakness, and difficulty in regaining full knee extension in the early post-operative period.[8]
Lind *et al.*[12] reported higher revision rates after ACL reconstruction with QT graft in the Danish registry, raising concerns about the safety of this graft. This high failure rate though, was attributed by the authors in a following study,[13] to the steep learning curve of the QT graft utilization.
This article aims to offer an additional technical note, highlighting safe minimal invasive QT harvesting using direct visualization with endoscopy.

TECHNIQUE

Patient positioning and marking

The patient is placed in the supine position on the operating room table and examination under regional or general anesthesia is performed. A tourniquet is placed as proximally as possible on the operative thigh and the knee is stabilized utilizing a side support at the level of the tourniquet and a foot stop to keep the knee at 90° of flexion. Patient positioning allows unrestricted, full range of knee motion. QT graft harvesting is accomplished with the knee flexed at 90°. After Esmarch exsanguination, the lower extremity is prepped and draped in the usual sterile fashion. For QT graft harvesting, the superior pole, medial, and lateral borders of the patella are identified and marked with the knee at 90° of flexion.

Arthroscopy

We routinely start the ACL reconstruction with standard diagnostic arthroscopy. We treat all concomitant pathology found, and once the ACL tear is confirmed, QT graft harvesting commences.

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Skin incision

Our technique is an evolution of the technique described by Slone *et al*.[7] A 2-cm longitudinal skin incision is made, starting just proximal to the center of the superior pole of the patella [Figure 1]. The incision is taken through the subcutaneous tissue to the level of the extensor mechanism. The prepatellar bursa and the paratenon are incised and the distal part of the QT is now visualized.

QT identification

The next step is to fully expose and identify the QT. QT is freed up with the aid of a gauze that is introduced through the skin incision proximally using a Cobb elevator [Figure 1]. Once a minimum space has been developed over the QT, dry arthroscopy is utilized. Farabeuf or other retractors are used to keep the space above the tendon accessible by the scope. Longitudinal traction of the Farabeuf retractors, to directly expose the QT, is not helpful since it causes collapse of the subcutaneous tissue onto the QT and as a result, the scope becomes ineffective.

The skin incision serves both as a viewing and working portal. Starting from the midline, the QT is completely freed up with a soft-tissue elevator, until the medial and lateral borders with the vastus medialis and vastus lateralis, respectively, are identified [Figure 2]. A motorized shaver blade (Torpedo, Arthrex Naples, FL) is used to remove any fat tissue debris that prevents clear visualization of the QT [Figure 2]. The arthroscopic dissection is continued proximally until the musculotendinous junction is identified. Now, the full length and width of the QT have been exposed [Figure 2]. Length and width measurement of the QT then follows with the aid of an arthroscopic ruler (Smith and Nephew, Andover, MA) [Figure 3].

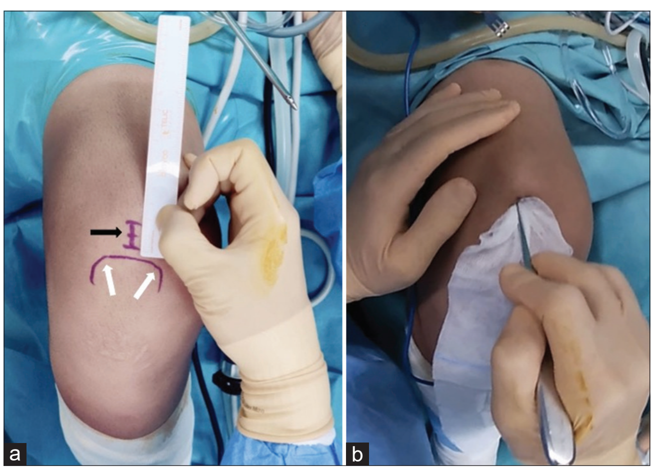

Figure 1: The patient is in a supine position with 90° of the right knee flexion (anterior view). (a) The superior, medial, and lateral borders of the patella are marked (white arrows). A 2-cm longitudinal incision starting just over the center of the superior pole of the patella is marked (black arrow). (b) Quadriceps tendon is freed up with the aid of gauze that is introduced through the skin incision proximally using a Cobb elevator.

QT cut

The cut of the tendon is carried out from proximal to distal utilizing a 9–11 mm in width double blade knife (Arthrex, Naples, FL) [Figure 4] depending on the size of the patient and the length of the footprint. The trajectory of the cut is determined and confirmed by direct vision with the scope. We aim at the central portion of the QT, without violating at any point the vastus medialis, vastus lateralis, or the musculotendinous junction. This is very important, since inadvertent injury of the QT borders will result in muscle fiber bleeding and hematoma formation. Moreover, wrong trajectory of the QT cut may lead to short or thin graft that could impair the result of the ACL reconstruction. In such a case, the option of re-harvesting a QT graft should be

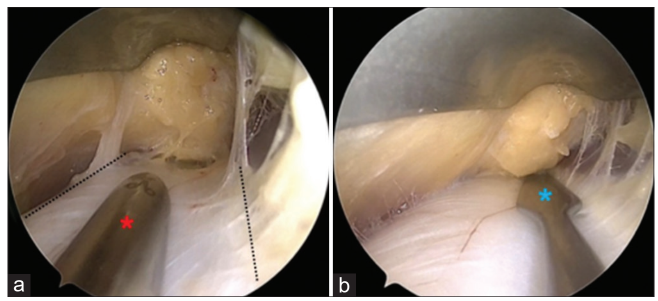

Figure 2: The patient is in a supine position with 90° of the right knee flexion. Quadriceps tendon endoscopy. The scope and an instrument are introduced through the 2-cm skin incision that serves both as viewing and working portal. (a) The quadriceps tendon is viewed and a motorized shaver (Arthrex, Naples, FL) (red asterisk) is used to remove any adhesions and debris that prevent identification of medial, lateral, and proximal tendon borders (dot lines). (b) The quadriceps tendon is viewed and a soft-tissue elevator (blue asterisk) is utilized to identify the proximal musculotendinous junction.

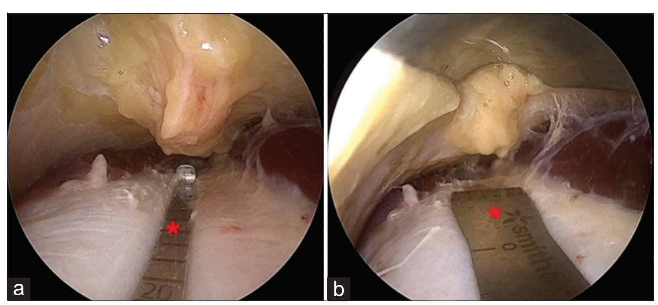

Figure 3: The patient is in a supine position with 90° of the right knee flexion. Quadriceps tendon endoscopic measurement. The scope and an arthroscopic ruler (Smith and Nephew, Andover, MA) (red asterisk) are introduced through the 2-cm skin incision that serves both as viewing and working portal. (a) The length of the quadriceps tendon is measured. (b) The width of the quadriceps tendon is measured.

evaluated. If this is not possible, harvesting a new graft as an adjunct or as the main graft is mandatory.

The strip of the QT is developed distally to the superior pole of the patella. The QT is released from the patella with a No15 blade [Figure 5], and the free end of the graft is grasped with an Allis forceps and whipstitched [Figure 5] with a non-absorbable No. 2 suture that will help as a traction suture for further manipulation and graft control.

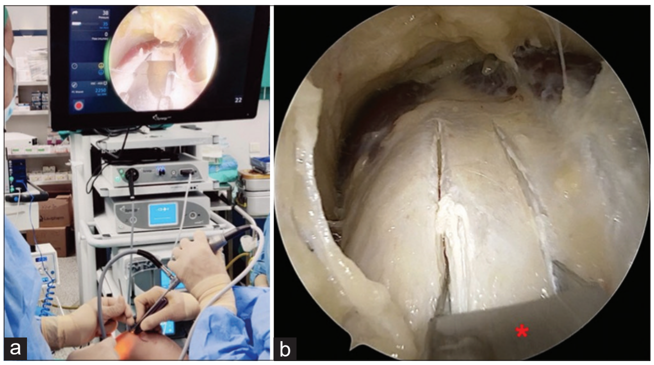

Figure 4: The patient is in a supine position with 90° of the right knee flexion. Quadriceps tendon, central third, and endoscopic cut from proximal to distal. The scope and a double-blade knife (Arthrex, Naples, FL) (red asterisk) are introduced through the 2-cm skin incision that serves both as viewing and working portal. (a). Outside view of the surgical step while the monitor displays the placement of the double-blade knife close to the musculotendinous junction, without violating the borders of the tendon. (b) Endoscopic view of proximal to distal quadriceps tendon, central third cut. The borders of the tendon are visualized and respected at all times.

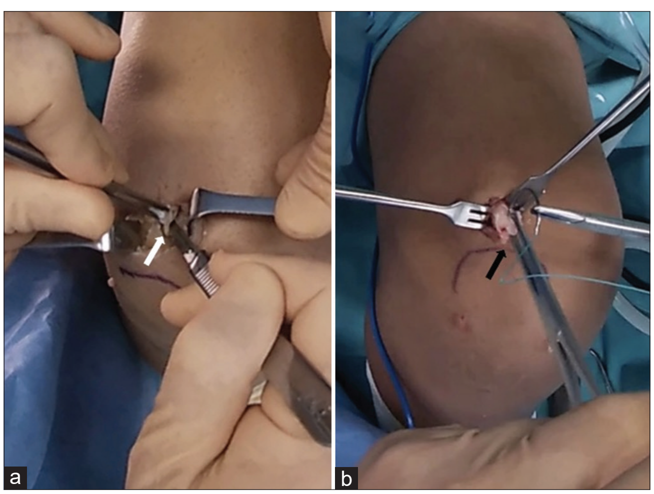

Figure 5: The patient is in a supine position with 90° of the right knee flexion. (a). The central third of the quadriceps tendon is released from the patella with a No15 blade (white arrow). (b) The distal, free end of the quadriceps tendon graft is held with an Allis forceps (black arrow) and whipstitched with a No. 2 non-absorbable suture (Ethicon) that will help in graft traction and manipulation.

QT graft release

The QT graft is then completely released from the surrounding tissues. Residual uncut parts of the QT strip are recognized and cut. To accomplish that, the traction suture is held, with light graft traction, along with the scope, while curved Metzenbaum scissors or arthroscopic punches are utilized to fully release the graft [Figure 6]. The medial and lateral borders of the tendon are visualized and protected at all times. Once we are sure that the graft's sides are cut and clear, the length of the graft is measured and amputated proximally near the musculotendinous junction with the scissors [Figure 7]. Alternatively, QT graft release and amputation can be accomplished in an "open fashion" using the concept of the "moveable window." In that case, Farabeuf retractors are utilized along with different knee flexion angles, to give access to the desired part of the graft. The most proximal part of the graft is reached with the knee in full extension and concomitant traction of the graft through the whipstitched distal part of the graft [Figure 7]. The QT graft is then passed to the back table for final measurement and preparation [Figure 8].

QT gap closure

The next step is to close the gap of the QT with side-to-side sutures. Suturing is carried out endoscopically utilizing simple shoulder arthroscopy instruments and techniques. The Scorpion Suture Passer (Arthrex, Naples, FL) is loaded with No. 2 non-absorbable sutures and the tendon is repaired with direct endoscopic visualization starting from proximal [Figure 9]. The knot is tied with the aid of a knot-pusher [Figure 9], exactly like in shoulder arthroscopy. We use a sliding, distal locking knot (Nicky knot) that is secured with the addition of 3–4 alternative half-hitches. Suture placement is continued distally in the same manner. Firm closure of the QT gap is very important to avoid fluid extravasation

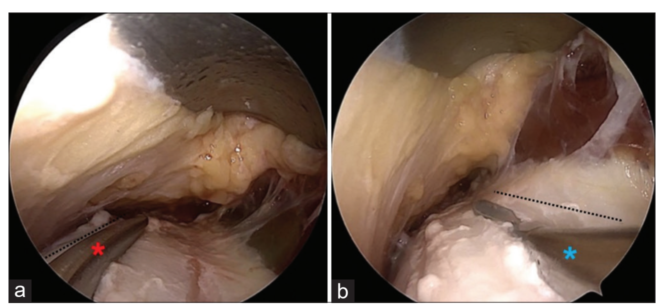

Figure 6: The patient is in a supine position with 90° of the right knee flexion. Quadriceps tendon graft endoscopic release. The scope and an instrument are introduced through the 2-cm skin incision that serves both as viewing and working portal. (a) A Metzenbaum scissors (red asterisk) is used to completely release the lateral side (dot line) of the quadriceps tendon graft. (b) An arthroscopic punch (blue asterisk) is used to completely release the medial side (dot line) of the quadriceps tendon graft.

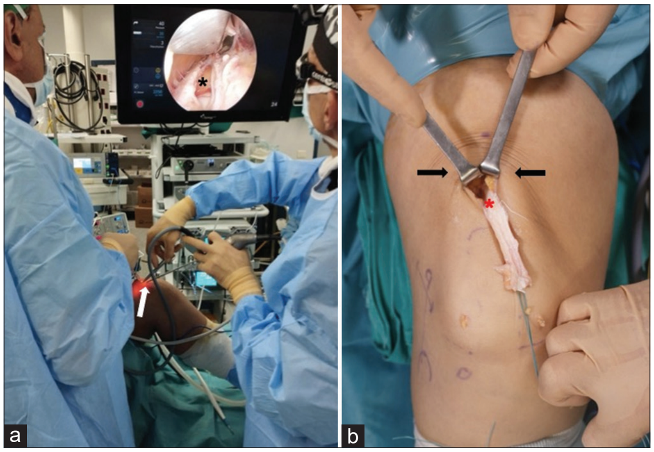

Figure 7: The patient is in a supine position with 90° of the right knee flexion, while quadriceps tendon graft proximal amputation was performed. (a). Endoscopic option. Outside view of the surgical step. The scope and scissors are introduced through the 2-cm skin incision (white arrow) that serves both as viewing and working portal. The assistant holds the graft in tension through the traction sutures. The monitor displays the quadriceps tendon gap (black asterisk) and the scissors amputating the graft proximally. (b) Open option in a different patient. During the learning curve of the surgeon, the concept of "moveable window" can be used. Without extending the skin incision, the quadriceps tendon graft can be released and amputated using two Farabeuf retractors (black arrows) and different knee flexion angles. The most proximal part of the tendon (red asterisk), for proximal amputation, can be reached with the knee in full extension.

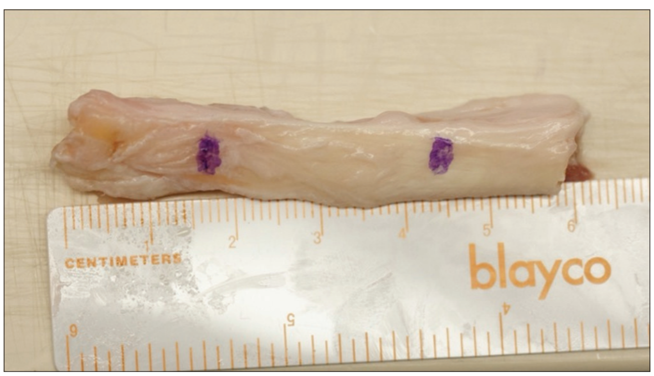

Figure 8: The quadriceps tendon graft is passed to the back table for final measurement and preparation. In this case, a 6-cm graft was harvested for an All-Inside ACL reconstruction, aiming for 15–20 mm graft incorporation and 20–30 mm intraarticular graft length.

that would make the following arthroscopic steps of the procedure impossible. Moreover, we believe that a repaired tendon behaves more favorably in the post-operative period in terms of extensor mechanism function.

QT gap closure is confirmed both endoscopically (scope above the tendon) as the last step of the QT graft harvesting and arthroscopically (scope under the tendon) as the first step of the arthroscopic procedure to follow [Figure 10]. .

Table 1: Advantages and disadvantages of endoscopic quadriceps tendon harvesting.

Advantages	Disadvantages
Minimal invasive technique	May require some extrasurgical time in the first cases
Can be accomplished with common surgical tools	May be not applicable for the inexperienced surgeon
All steps of the procedure are completed under direct visualization	
Minimizes the risks of quadriceps tendon graft harvesting	
Adds no extra cost and morbidity	
Increases surgeons' confidence	

The advantages and disadvantages of endoscopic quadriceps tendon harvesting are presented in [Table 1].

DISCUSSION

Biomechanical and clinical studies have been very promising for the utilization of the QT graft in ACL reconstruction and the interest in this graft has been remarkably grown. The ultimate failure load was found to be 1725–2160 N for the native ACL, 2977 N for patellar tendon graft, 2119–2352 N for QT graft, and up to 4090 N for hamstring tendon graft.[14] The stiffness of the QT graft was found to be nearly double of the native ACL (466.2 N/mm vs. 242 N/mm) with the greatest strength of collagen alignment compared to patella tendon and hamstrings grafts.[15]

A large systematic review and meta-analysis examining quadriceps tendon (QT) versus bone-patella tendon-bone (BPTB) and hamstrings tendon (HT) autografts, demonstrated equivalent clinical results in terms of graft failure, stability, and IKDC score. The QT group was found to have significantly less donor site pain than the BPTB group ($P < 0.0001$) and a greater mean Lysholm score than the HT group ($P = 0.03$).[6]

Despite the aforementioned data, the QT graft still remains the least popular one. Unfamiliarity with harvesting, fixation issues and cosmesis are probably the main reasons for this. Many minimal invasive techniques of harvesting and graft fixation have been published lately, trying to address these concerns.[7-11] Nevertheless, QT graft harvesting is considered to have a steep learning curve that may compromise the results in low volume centers.[13]

Common complications of QT graft harvest include hematomas, weakness of the quadriceps, and loss of knee extension in the early post-operative period and, rarely, rupture of the knee extensor apparatus.[8] These complications

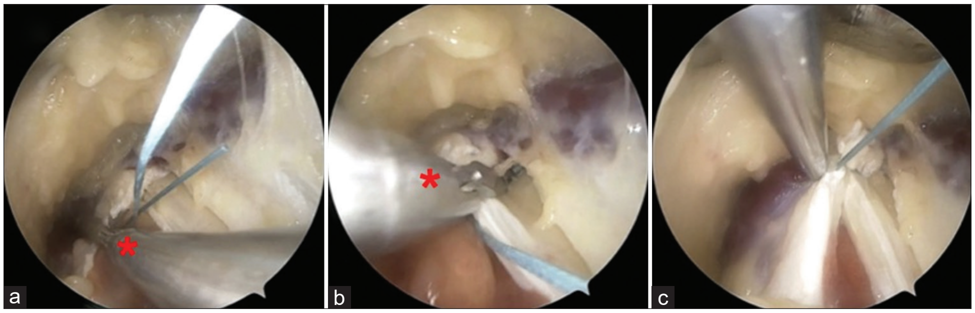

Figure 9: The patient is in a supine position with 90° of the right knee flexion. Endoscopic repair of the quadriceps tendon gap from proximal to distal. The scope and an instrument are introduced through the 2 cm skin incision that serves both as viewing and working portal. (a) A scorpion suture passer device (Arthrex, Naples, FL) (red asterisk) is used to pass the first limb of a No. 2 non-absorbable suture (Ethicon). (b) The second suture limb is passed in the same manner (red asterisk). (c) An arthroscopic sliding knot and a knot pusher are used to tie the suture.

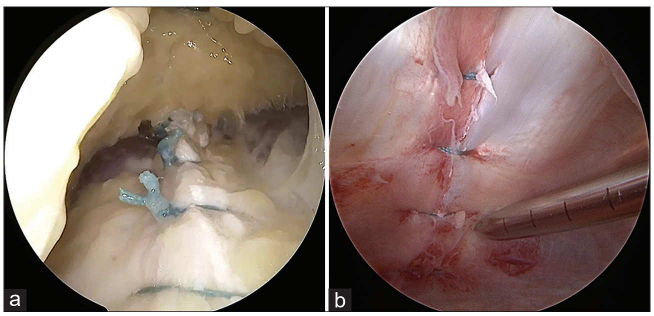

Figure 10: Right knee. Final result of the quadriceps tendon gap repair. (a) Endoscopic view. Supine position with the knee flexed at 90°. The scope is introduced through the 2-cm skin incision that serves as viewing portal. (b) Arthroscopic view. Supine position with the knee fully extended. The scope is introduced through the standard anterolateral portal and advanced under the quadriceps tendon.

can be avoided if optimal graft harvesting technique is applied.

The main advantage of our technique is the introduction of direct visualization of all surgical steps of the procedure, without extending the skin incision. We strongly believe that this is a crucial issue of safe QT graft harvesting that will increase the surgeon's confidence and minimize the complication rate.

TRAJECTORY

The use of endoscopy to assist graft harvesting, so far, is restricted to tendon identification. Tendon cutting is carried out using a double knife or tendon stripper and proximal amputation is accomplished with a tendon cutter. All these surgical steps are actually performed "blindly." The optimal use of a double knife or a tendon stripper/cutter probably requires a steep learning curve with the risk of having a short graft or a weak graft if the instrument is inadvertently guided in the wrong trajectory.

Slone *et al*.[7]proposed marking of the skin to indicate the length and the side-to-side (coronal) course of the QT. Nevertheless, the tip of the stripper is not visualized during advancement and as a result, the chance of following a non-optimal route cannot be prevented in non-experienced hands. The portion of the QT that is left attached to the vastus medialis is as low as 1 mm in width and can be easily violated even with the smallest diversion of the optimal direction of the tendon stripper. In this scenario, the graft could be shorter than desired and planned, and bleeding and hematoma formation could occur.

However, it is not only the side-to-side (coronal plane) misdirection that could take place. The stripper could also be accidentally advanced in the wrong anteroposterior (sagittal plane) route, leading to a thin graft, or a graft with a non-unanimous thickness or, even worse, a short graft.

Finally, the theoretical risk of rectus tendon retraction if the proximal myotendinous junction is violated cannot be excluded if the graft amputation is performed without direct visualization.

The uncertainty of these surgical steps could be a drawback for many surgeons to adopt the QT as their primary choice for ACL reconstruction.

GAP REPAIR

The QT is a very important structure of the knee extensor mechanism, and with harvesting of the central one-third of the tendon, treating the QT gap is an issue. So far, there is no consensus on whether the QT defect should be left alone or repaired. Cole *et al*.,[16] in a systematic review, concluded that it is unclear with the current data if there is a difference in outcomes based on the technique used.

Evaluation of the extensor mechanism in cadaveric samples showed that the harvested QT could withstand greater tensile loads than the entire intact patellar tendon.[4] This is very important in the early post-operative period where full knee extension and early quadriceps muscle activation are desired.

It is our belief that QT gap closure contributes to better biomechanical behavior of the QT postoperatively. Moreover, gap repair seals the joint capsule, keeping all the released growth factors intra-articularly and of course prevents fluid extravasation during arthroscopy. As a result, we recommend and routinely repair the QT gap with strong non-absorbable sutures. The completion of the QT gap endoscopically adds no extra morbidity to the procedure and allows the surgeon to proceed with no extra restrictions to the rehabilitation regime.

CONCLUSION

Improving and simplifying QT harvesting by endoscopic means, will make this graft increasingly attractive, not only for revision surgery, but also for primary ACL and PCL reconstruction.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The author(s) confirms that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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