

INDIVIDUALISED, ANATOMIC ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

– Written by *Thierry Pauyo, Marcio Bottene Villa Albers and Freddie H. Fu, USA*

Anterior cruciate ligament (ACL) reconstruction surgery has emerged as one of the most frequently performed orthopaedic procedures in the United States. It is estimated that every year, about 43 ACL reconstructions are performed per 100,000 people¹. While ACL reconstruction is nowadays readily performed, the first ACL reconstruction surgery was described in the early 1900s by Ernest William Hey Groves, an English general surgeon, who used the iliotibial band to reconstruct the ACL². During the following century, attempts to stabilise the ACL-injured knee transformed the surgical technique from an open procedure to culminate in what we consider today the gold standard; arthroscopic reconstruction – first developed in 1980³. This article discusses a new concept in arthroscopic ACL reconstruction surgery,

where the basis of treatment is centred on each patient's individual native anatomy.

ANATOMY OF THE ANTERIOR CRUCIATE LIGAMENT

The anatomy of the ACL has been thoroughly studied in cadaveric dissections revealing the existence of two distinct bundles: anteromedial (AM) and posterolateral (PL) (Figure 1). The kinematics of the knee are affected by the function of these two bundles, which provide stability in different positions of the knee. The AM bundle is tightest during knee flexion, while the PL bundle is tightest during knee extension and is believed to play a critical role in controlling rotational stability. While the two bundles exhibit different kinematic behaviours during knee motion, they function synergistically as one structure.

The AM and PL bundles are present during early foetal life and have been identified in foetal knees as early as 17 weeks of gestation⁴. Furthermore, the septum dividing the two bundles has been found to harness stem cells, which may suggest a potential role in the healing process of ligament injury⁵.

While the anatomy of the ACL clearly defines two bundles, the early surgical reconstruction procedure focused on restoring one ACL bundle to provide knee stability. It was not until 1994 that arthroscopic double-bundle (DB) ACL reconstruction was first described and introduced into orthopaedic surgical practice^{6,7}. While the majority of surgeons currently perform single-bundle (SB) ACL reconstruction, understanding of the native anatomy of the knee, with two distinct bundles, is primordial to comprehend the

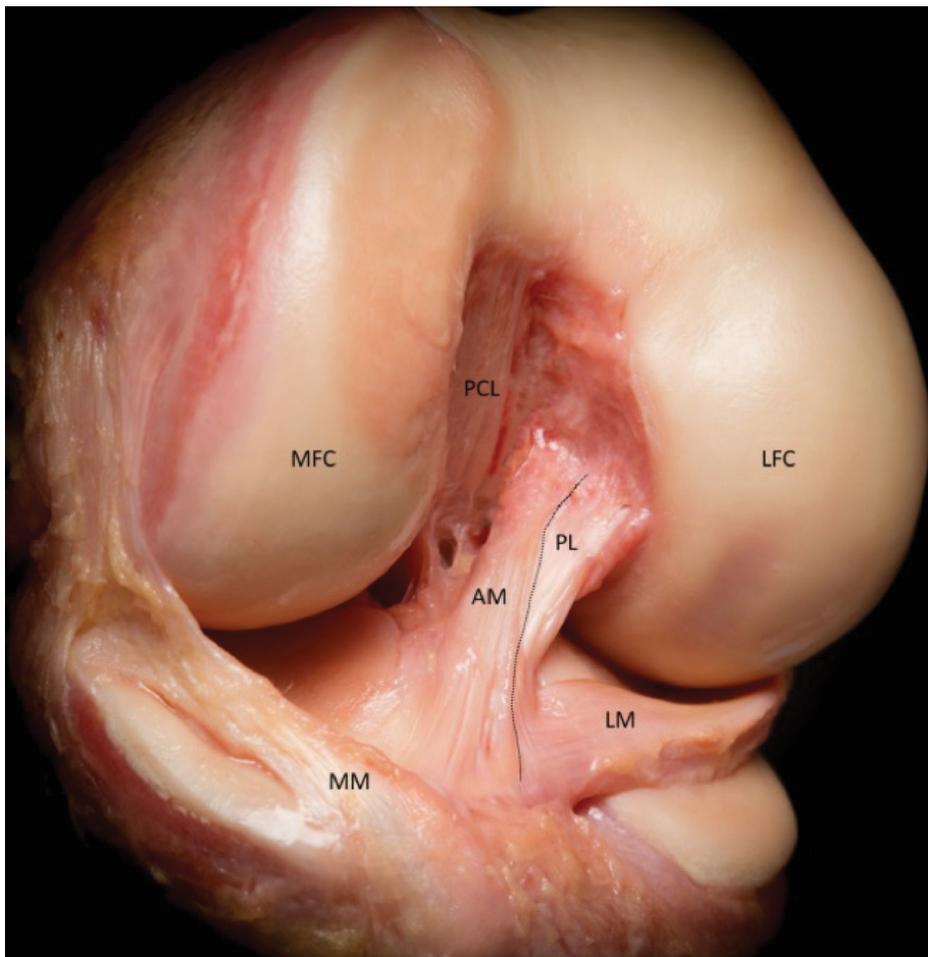


Figure 1: Left knee dissection showing the Anterior Cruciate Ligament functional bundles, anteromedial (AM) and posterolateral (PL), separated by a septum (dotted line). Note the close relation between the anterior horn of the lateral meniscus (LM) and the PL bundle of the ACL.

concept of individualised anatomic ACL reconstruction.

NON-OPERATIVE TREATMENT

While there is an emphasis in the literature on ACL reconstruction as the standard of care for ACL injury, there is some literature that supports non-operative treatment and rehabilitation for a particular subset of patients. In a cohort study of 125 patients, Moksnes et al compared non-operative to operative treatment of ACL surgery⁸. They found no difference in episodes of giving way, activity level and overall muscles evaluation between the two groups. Furthermore, in a randomised controlled study of 121 individuals, Frobell et al evaluated structured rehabilitation and early ACL reconstruction versus structured rehabilitation with an option of delayed ACL reconstruction⁹. They found that only 39% of the optional delayed ACL group underwent subsequent ACL reconstruction.

Furthermore, there were no significant differences between the two groups with patient-reported outcomes. While these studies define successful outcomes with non-surgical treatment of ACL injury, a large body of literature supports the reconstruction of the injured ACL to prevent meniscal injury and pathological knee laxity^{10,11}. Ultimately, the non-operative approach is typically employed in sedentary patients with limited knee instability. Furthermore, elderly patients with radiologic evidence of degenerative changes in the knee should be considered for a non-operative rehabilitation programme.

SURGICAL INDICATIONS

ACL reconstruction surgery should be considered in patients younger than 40 years old with knee instability. However, there is some recent evidence that ACL reconstruction in patients older than 60 years old without arthritis has shown good

functional results¹². The patient's history of the knee 'giving way' while performing sports activities and a physical exam consistent with pathological anterior tibial laxity or rotation instability are indications for surgical treatment. It is fundamental to obtain a thorough understanding of the patient's pre-injury level of activity, type of sport practiced and objectives in returning to pre-injury level of sport. The treatment of children and adolescents with ACL injury remains controversial with recent evidence demonstrating that ACL reconstruction offers a reduction in the risk of subsequent meniscal tear with minimal risk of growth disturbance^{13,14}.

INDIVIDUALISED ANATOMIC ACL RECONSTRUCTION CONCEPT

The aim of individualised anatomic ACL reconstruction is to functionally restore the ACL to its native dimensions, orientation and insertion sites according to an individual's particular anatomy¹⁵. Furthermore, the initial individual evaluation determines whether the patient requires surgical treatment or if non-operative treatment and rehabilitation are indicated. When surgery is indicated, the graft type, size, surgical technique and postoperative care are tailored to match the patient's particular anatomy and functional needs. For surgeons, there are four fundamental principles which govern individualised anatomic ACL reconstruction:

1. Restoration of the two functional bundles of the ACL: AM and PL.
2. Restoration of the native insertion sites.
3. Appropriate tensioning of the AM and PL bundles.
4. Correctly matching the patient's ACL graft size with native ACL ligament size.

Indeed, there is some variation in ACL insertion site size in the general population. Kopf et al, in an anatomic study of intraoperative measurements, determined that the tibial insertion site varied from 12 to 22 mm while the femoral insertion site varied from 12 to 20 mm¹⁶. Although, the majority of surgeons aim to reconstruct the ACL with a 10 mm single bundle ACL graft, it is evident that this 'one size fits all' approach overlooks the innate differences of ACL footprint size present in the general population.

OPERATIVE TREATMENT

Treatment of patients with an ACL-deficient knee for which surgical treatment is warranted begins immediately following diagnosis. Preoperative rehabilitation plays a critical role in affecting the postoperative outcome of ACL reconstruction. Mayr et al, in a study of 225 patients, illustrated that a preoperative deficit in knee range of motion (ROM) and the presence of a knee effusion have led to the development of arthrofibrosis following ACL reconstruction¹⁷. Furthermore, Eitzen et al showed in a cohort study of 73 patients, that preoperative deficit in quadriceps strength affected mid-term postoperative functional outcomes¹⁸. This shows the importance of regaining full knee ROM along with quadriceps control via straight leg raises and resolving knee effusion before surgery. Among surgeons, the first school of thought is generally to delay surgery for 3 weeks post-injury in order to achieve these preoperative goals and minimise the chances of postoperative arthrofibrosis¹⁰. There is however, a recent study that has shown there is no added risk in performing acute ACL reconstruction¹⁹. The second school of thought believes that acute surgical ACL reconstruction diminishes the subsequent risk of meniscal

tear and improves postoperative ROM. In a recent study on the impact of timing of ACL reconstruction on postoperative outcomes, Herbst et al showed that acute surgery decreases postoperative extension deficits¹⁹.

DIAGNOSTIC IMAGING

Following the diagnosis of instability acquired from the patient's history and physical examination, diagnostic imaging is initiated with knee radiographs. These help the physician evaluate the presence of degenerative disease, the presence of a Segond fracture, as well as anterior translation of the tibia relative to the femur. The imaging also enables the proper evaluation of the growth plates in the case of ACL injury in a young patient. The individualised patient evaluation utilises magnetic resonance imaging (MRI) both to evaluate ACL injury and measure the tibial insertion site dimensions. Guenter et al performed an MRI study of 126 patients and determined that preoperative MRI evaluation of the ACL could reliably predict ACL size as well as insertion site dimensions measurements²⁰. Therefore, preoperative MRI is used to estimate the ACL graft size in order to represent between 50 and 70% of the native tibial insertion site. This will

ensure that the ACL graft is appropriately-sized and correctly matches the native ACL in order to prevent overstuffing the femoral notch especially in the case of an individual with a narrow notch.

INDIVIDUALISED SINGLE-BUNDLE AND DOUBLE-BUNDLE CONCEPT

Once the proper imaging has been obtained, the surgeon must decide to either perform a single-bundle (SB) or double-bundle (DB) ACL reconstruction. The preoperative MRI evaluation guides the surgeon on whether to perform a SB or DB ACL reconstruction (Figure 2). The length of the tibial footprint is measured at its midline axis using coronal and sagittal images, then the measurements are referenced against the normal distribution of ACL tibial insertion (Figure 3). On the basis of these measurements, a SB reconstruction is indicated if the tibial insertion site is <16 mm and a DB reconstruction is planned if the length of the insertion is 16 mm or more²¹. The individual, anatomic ACL reconstruction aims to match the ACL graft with a patient's native anatomy to prevent oversizing the ACL graft and overstuffing the femoral notch – potentially causing impingement, limited ROM and early graft failure. During the initial diagnostic arthroscopy, intraoperative measurements of the tibial insertion sites are made to corroborate the preoperative measurements and confirm the reconstruction method. In the case of an ACL tibial insertion site that measures < 16 mm, a SB ACL reconstruction is recommended to correctly match the ACL graft with the patient's anatomy. The other factors that determine SB ACL reconstruction are; a narrow notch (<14 mm), open growth plates and multi-ligamentous injury²². Recent meta-analyses comparing both SB and DB ACL reconstruction found improved postoperative knee stability while showing no difference in risk of graft failure^{23,24}. We believe the decision to perform SB versus DB graft should be made based on tailoring the appropriate ACL graft to match the patient's native ACL anatomy (Figure 4).

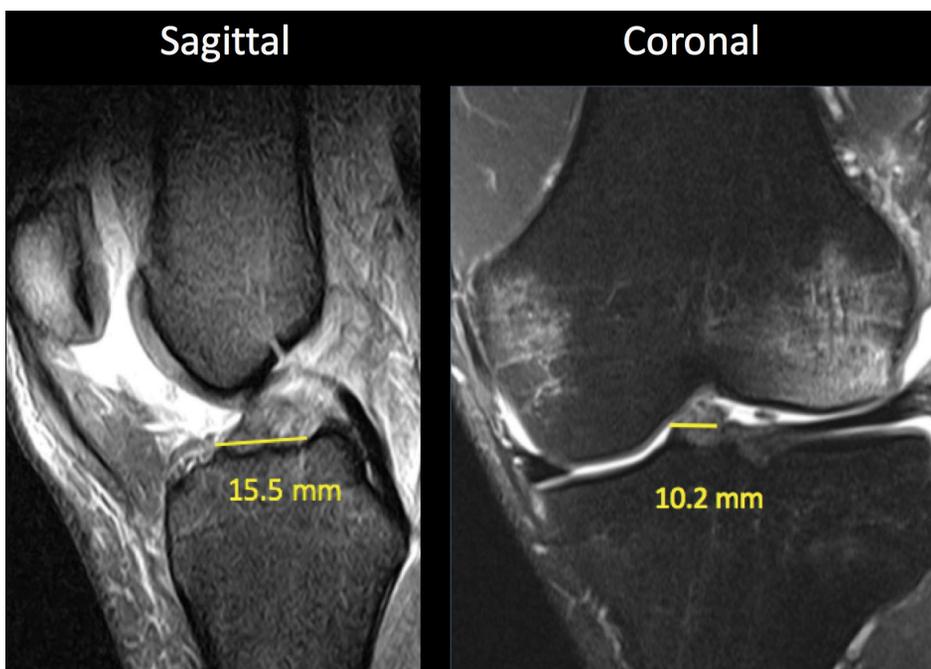


Figure 2: The preoperative MRI evaluation of the ACL-injured knee. The length of the tibial insertion is measured at the mid axis of the tibial insertion site on sagittal and coronal MRI.

GRAFT SELECTION

Selection of the appropriate graft for individualised, anatomic ACL reconstruction is one of the most important steps in the

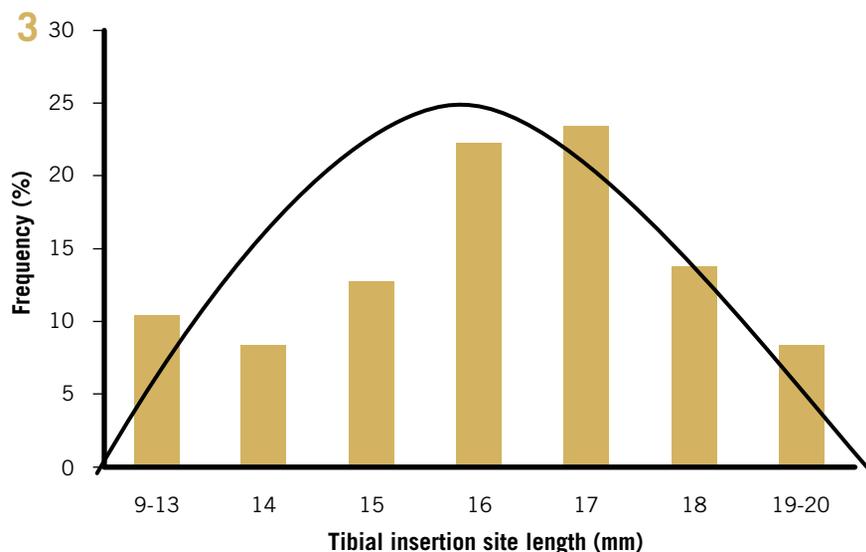


Figure 3: Distribution of the measured tibial insertion site size of the normal distribution of the anterior cruciate ligament.

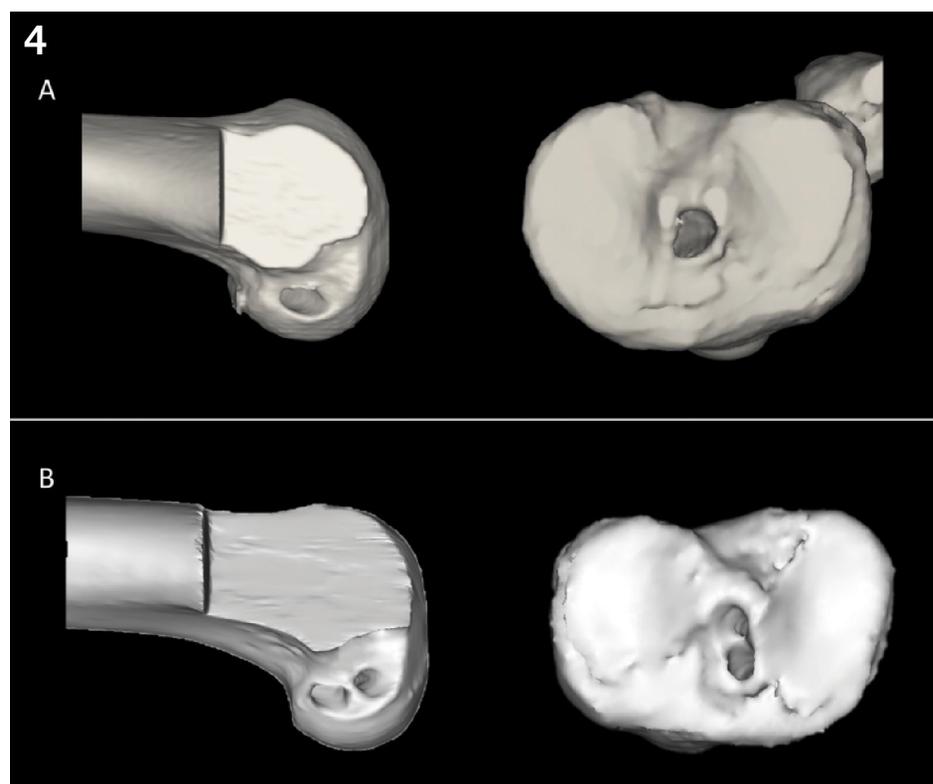


Figure 4: Three-dimensional computed tomography of the left knee. (a) The anatomic positioning of femoral and tibial tunnels in a single-bundle ACL reconstruction. (b) The anatomic positioning of femoral and tibial tunnels in a double-bundle ACL reconstruction.

surgical planning of the procedure and is finalised during the intraoperative evaluation of the joint. While it is important to understand the advantages and disadvantages of each graft option, the individualised concept of ACL reconstruction selects the appropriate graft type to match the native ACL anatomy of

the patient. This will ensure that the correct graft size is utilised to best correlate with the size of the native ACL. The hamstring tendon should be used when the femoral notch is narrow and in cases where the tibial footprint and the predicted size of the graft are small. Conversely, the quadriceps tendon and patella tendon can be used

when the notch is wider and with a larger ACL native tibial footprint. It is important to note that the patella tendon should not be used if maximum thickness of the tendon on sagittal cuts is less than 5 mm. Furthermore, the quadriceps tendon is considered adequate if the maximum thickness on sagittal MRI exceeds 7 mm. In addition, the individualised, anatomic ACL reconstruction technique uses the known characteristics of each graft option in order to match the native ACL size and the predicted appropriate graft size.

The hamstring tendon autograft is readily used by the surgical community for ACL reconstruction. It offers the advantages of a proven track record in outcome studies with low morbidity during the harvesting procedure²⁵. The disadvantages lie in the variability in size of the harvested graft and in the soft tissue fixation, which may require a longer postoperative time period before returning to sports. The patella tendon autograft has been well studied in contact athletes and provides a reliable graft, with bone-to-bone healing in the tunnels, which may shorten the time to return to sports²⁶. There is, however, a potential for patella fracture during harvest and a risk for postoperative anterior knee pain. Studies have found no significant differences in objective outcomes between hamstring autograft and bone patella tendon bone autograft^{10,27}. The quadriceps tendon autograft has seen an increase in use recently while providing a reliably sized graft with the potential to harvest a bone plug and enable bone-to-bone tunnel healing²⁸. There is a risk of quadriceps tendon deformity and weakness that should not be overlooked while deciding which graft option to use.

The allograft is an appropriate option in the setting of multi-ligamentous knee injury as well as in the older patient population. One disadvantage of this graft is the possible risk of disease transmission and subsequent infection²⁸. Furthermore, allograft ACL reconstruction in younger patients has been shown to lead to premature graft failure²⁹.

The final decision on graft selection during individualised, anatomic ACL reconstruction is based on graft characteristics and size to best match the patient's native anatomy.

INDIVIDUALISED ANATOMIC RECONSTRUCTION PROCEDURE

The arthroscopic procedure uses three portals to correctly perform the required steps (Figure 5). The anterolateral portal is mainly used as a viewing portal, while the central and accessory medial portals are used both for instrumentation and to view the ACL footprints from different vantage points. During the arthroscopic procedure, the surgeon will identify the ACL remnant and remove the ruptured ACL with a scalpel, effectively exposing the ACL footprint and its fibres. The surgeon will then measure the dimension of the ACL tibial footprint with an arthroscopic ruler (Figure 6). This is done by measuring the length of the tibial insertion along the major axis of the insertion sites, and the width at its widest diameter²¹. As mentioned above, the ACL graft size should measure between 50 to 70% of the ACL tibial footprint and the intraoperative measurements are used to corroborate the preoperative MRI graft size predictions and reference to the normal distribution of ACL in the population (Figure 3).

The next step consists of measuring the notch size. The surgeon should carefully evaluate the femoral notch and correctly identify low and narrow notches, which could present a challenge while passing a graft with a bone block in the femoral tunnel. Following the graft harvest, the surgeon positions anatomic tunnels in both the femoral and tibial footprint and should use flexible drill guides in order to drill a longer femoral tunnel (Figure 7). Ideally, the femoral tunnel is drilled while the knee is in maximal flexion to facilitate anatomical femoral tunnel position and maximise femoral length. Conversely, the anatomic tibial tunnel is positioned with the knee at 90° of flexion and with the tibial guide set at 55° of inclination. Following the passage of the ACL graft, it can be secured in place with a variety of fixation methods. We recommend suspensory fixation, femoral fixation, and interference screw or post fixation for the tibial portion of the graft. It is important to obtain intraoperative pictures from all portals to fully appreciate the correct placement and sizing of the ACL graft (Figure 8).

POSTOPERATIVE CARE AND REHABILITATION

Nowadays, 95% of ACL reconstruction surgery is performed as an outpatient surgery where patients return home on the same day². This change in the trend is mostly due to improvements in perioperative care, including the approach to anaesthesia and analgesic care – but also because of changes in postoperative rehabilitation as well as in patients' expectations³. Postoperative care is initiated directly after surgery. The knee is placed in a knee immobiliser and the patient is discharged home with partial weight-bearing restriction in extension. During the first 6 days, the focus lies on pain and oedema control while initiating straight leg raises and ankle pumps. The rehabilitation protocol is started after the first week with passive ROM and a controlled progression to full ROM. The brace is typically maintained for 6 weeks, when the patient usually exhibits sufficient quadriceps control to perform straight line walking. The patient is slowly progressed to a stationary bike once the ROM has

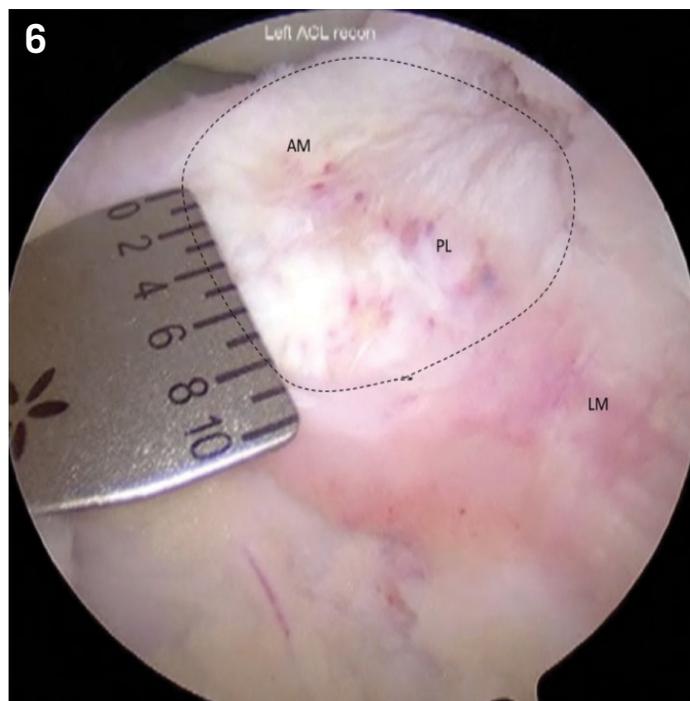


Figure 5: Left knee arthroscopic portals for an Individualised ACL reconstruction procedure. Lat=anterolateral portal; C=central portal; AM=accessory anteromedial portal.

Figure 6: Arthroscopic view, from the anterolateral portal, of the tibial insertion site of the ACL. A simple ruler is used to measure the length and width of the ACL stump.

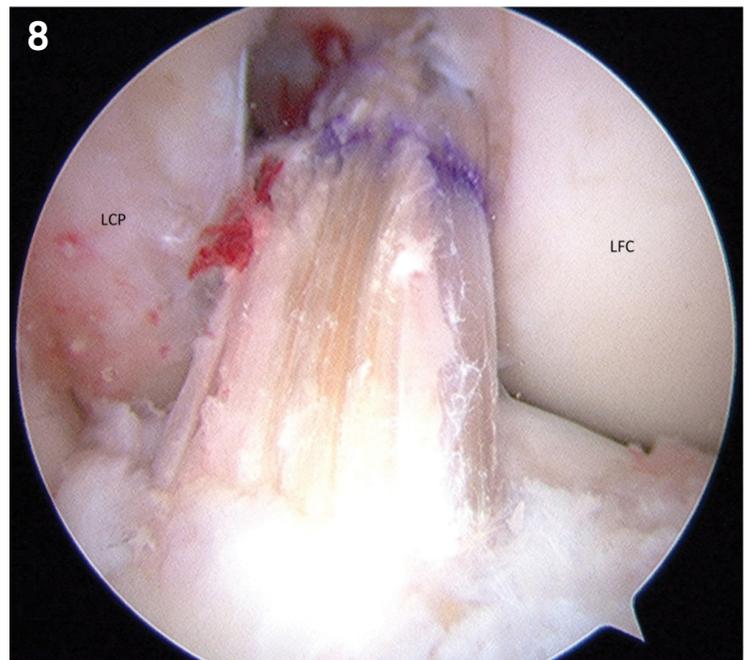
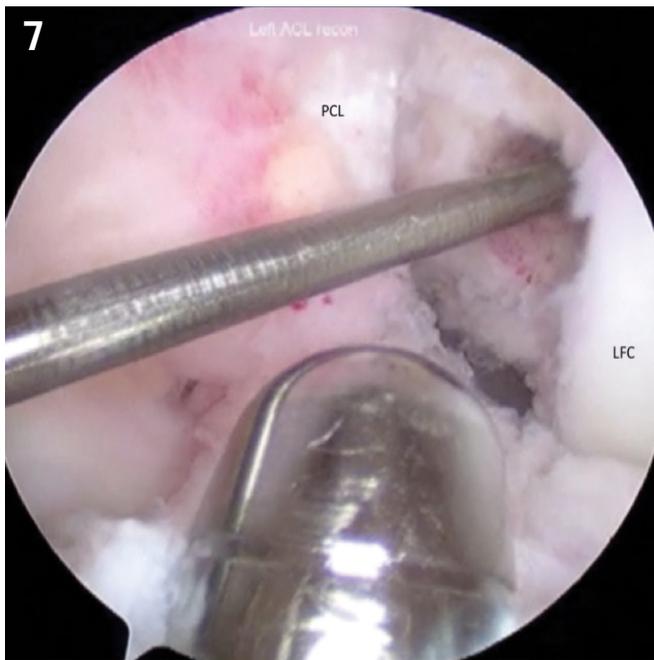


Figure 7: Arthroscopic view, from the central portal, of the femoral tunnel with drilling pin and tibial tunnel dilator. The ACL graft will later be passed through the tibia into the femoral tunnel before fixation.

Figure 8: Arthroscopic view from the central portal showing the graft in anatomical position.

improved and can start jogging at 3 months after surgery. The return to pivoting and cutting non-contact exercises are allowed no sooner than 6 months postoperatively. This allows adequate time for the graft to incorporate and mature to withstand the increased demands^{30,31}. A progressive return to sports is generally considered around 9 months postoperatively, when the patient has returned to full strength.

RETURN TO SPORTS

The time frame for a safe return to sports has not been established. While there is no evidence supporting its use, many physicians would recommend athletes to wear a functional knee brace during the first two years postoperatively³². Overall, 80 to 85% of patients are expected to have a successful return to pre-injury sports³³. While the ultimate goal of individualised, anatomic ACL reconstruction is to enable the athlete to return to their pre-injury sport, both the surgical procedure and postoperative rehabilitation affect surgical outcomes. We have previously discussed the importance of preoperative rehabilitation in restoring ROM and quadriceps muscle control. Moreover, the graft choice can influence an earlier return to sport when bone-to-bone healing is achieved in the tunnels with patella tendon bone autograft

or quadriceps tendon bone autograft. Finally, adherence to an adequate postoperative rehabilitation protocol has an important role in improving outcomes³⁴.

The individualised, anatomic ACL reconstruction technique is a novel concept geared to recreate the patient's native ACL anatomy. While it has shown promise conceptually in adapting the graft type, sized to each particular individual, there is still research to be done in evaluating long-term outcomes in regard to providing knee stability, improving patient-reported outcomes and return to pre-injury levels of activity.

References available at www.aspetar.com/journal

Thierry Pauyo M.D., F.R.C.S.C.
Sports Medicine Fellow
University of Pittsburgh Medical Center
Pittsburgh, PA, USA

Marcio Bottene Villa Albers M.D.
Research Fellow
University of Pittsburgh of Pittsburgh
Medical Center
Pittsburgh, PA, USA

Freddie H. Fu M.D., D.Sc. (Hon), D.P.S. (Hon)
Chair and David Silver Professor,
Department of Orthopedic Surgery –
University of Pittsburgh
Pittsburgh, PA, USA

Contact: ffu@upmc.edu