Operative Techniques in
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Anatomy of the Anterior Cruciate Ligament

Thore Zantop, MD,*,† Wolf Petersen, MD,† and Freddie H. Fu, MD, DSc (Hon), DPs (Hon)*

An internet-based literature review using the catalog of the National Library of Medicine for the keyword "anterior cruciate ligament" results in 5884 hits, thus reflecting the high importance of basic and clinical research. To achieve a satisfying surgical outcome after anterior cruciate ligament (ACL) reconstruction, a basic knowledge of the anatomy of the ACL is essential. The early manifestation of the ACL in the fetal knee joint suggests that the knee joint is early under the stabilization of the ACL. The origin of the ACL is at the medial surface of the lateral femoral condyle and runs distal–anterior–medial to the insertion at the medial tibial eminence. In the literature, a 2-bundle description of the ACL into anteromedial and posterolateral bundle has been accepted as a basis for the understanding the function of the ACL. Length and diameter of the native ACL may play an important role for choosing the type of graft and for the preparation of the graft. Microscopically, femoral origin and tibial insertion have the structure of a chondral apophyseal enthesis and can be separated into 4 layers. The collagen fibrils of the ACL are surrounded by connective tissue forming multiple fascicles. Proximal and distal vessels support a synovial plexus from which small vessels run into the ligament and align longitudinally parallel to the collagen bundles.
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Because of the increasing importance of sports activities, the incidence of anterior cruciate ligament (ACL) ruptures has risen during the last years. Currently, a large number of ACL reconstructions are performed each year around the world, with estimated 75,000 to 100,000 cases in the United States alone.[1] Therefore, the ACL has been one of the most frequently studied structures of the musculoskeletal system during the last decades. Biomechanics of the intact and ACL replacement graft, different types of grafts, mechanism of failure, treatment, surgical techniques, and postoperative rehabilitation protocols have been intensively studied.

Nevertheless, the most fundamental aim of ACL reconstruction is to restore the normal ACL anatomy as closely as possible. There is general agreement that current ACL reconstruction techniques using autologous tendon grafts anchored in one femoral and one tibial tunnel achieve this goal only to some degree. Recently, a more anatomical approach to reconstructing both bundles of the ACL has evoked the interest of many surgeons. To achieve a satisfying surgical outcome after ACL reconstruction, basic knowledge of the anatomy of the ACL is essential. This article focuses on the anatomy of the native ACL, its insertions, and gross as well as microscopic findings.

Historical Background

One of the first anatomical descriptions of the ACL can be found written on an Egypt papyrus scroll that dates back to 3000 BC. Hippocrates (460-370 BC) described a subluxation of the human knee caused by injury of the ACL; however, the name of the ligament was applied by Claudius Galen of Pergamon as "ligamenta genu cruciate" (129-199 BC). Weber then described the first attempts of biomechanical investigations of the human knee joint and cruciate ligaments in 1836[2] followed by Bonnet, who presented the mechanisms of ACL injury in 1850 in which the ACL was found to most commonly rupture from the femoral insertion site.[3] The beginning of surgical treatment of ACL injuries can be dated back to 1898 when W. Battle sutured a torn ACL.[4] The revolutionary technique of using autologous tendon for the reconstruction of the ACL was developed by V. Nicoletti in 1913 in a cadaveric study[5] and performed in a human in 1914 by the Russian surgeon Grekow.[6] Over time, the surgical technique for ACL reconstructions emerged from arthrotomy to arthro-

*Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA.
†Department of Trauma, Hand, and Reconstructive Surgery, Westfalian Wilhelms University, Münster, Germany.
Address reprint requests to Freddie H. Fu, MD, DSc (Hon), DPs (Hon), Chairman and David Silver Professor, Department of Orthopedic Surgery, University of Pittsburgh Medical Center, Kaufmann Building, 3471 Fifth Avenue, Suite 1011, Pittsburgh, PA 15213. E-mail: ffu@upmc.edu

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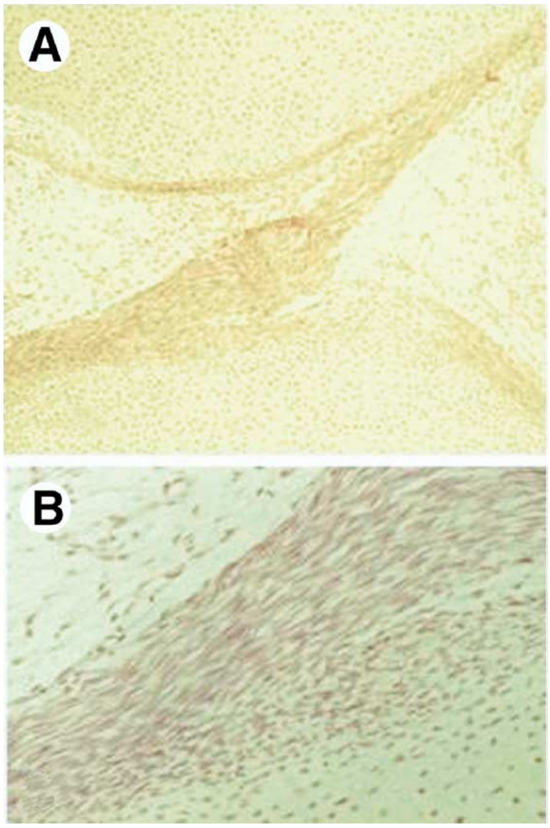

Figure 1 (A) Fetal ACL, 10th week after gestation. Note the early organization of the ACL between femur and tibia. (B) Fetal ACL, 10th week after gestation. The fibroblasts within the ligament are aligned to the axis of strain of the ACL.

scopic surgeries. In 1921 Bircher was able to scope a human knee for the first time[7]; however, it took until 1981 since Dandy reported about the first arthroscopic ACL reconstruction.[8] Nowadays, reconstruction of a torn ACL in an active patient can be considered to be state of the art. In 2004, an internet based literature review using the catalogue of the National Library of Medicine for the keyword "anterior cruciate ligament" results in 5884 hits thus reflecting the high importance of basic and clinical research.

Embryology

The knee joint starts its formation from vascular mesenchyme between femur and tibia in the fourth week of gestation between the blastoma of femur and tibia.[9] A distinct amount of fibers of ACL fibers appear in approximately the 8th week after gestation[10] (Fig. 1). At this time, the fibroblasts within the ligament are already aligned to the axis of strain of the ACL (Fig. 1). By 9 weeks, the cruciate ligaments are composed of numerous immature fibroblasts having scanty cytoplasm and fusiform nuclei. Over the next weeks, the major change in the addition to growth, is the increase in vascularity. During this time the fusiform fibroblasts express high amounts of the angiogenic factor vascular endothelial growth factor (Fig. 2).[11] The expression of vascular endothelial growth factor is largely downregulated after birth, but this factor is strongly re-expressed during the remodeling of autologous tendon grafts used for ACL reconstruction.[11] After week 20, the remaining development consists of marked growth with little change in form. In a recent publication, Tena-Arregui and coworkers arthroscoped the knee joint of fetuses with a gestational age of 24 to 40 (±2 weeks) and found the appearance of the ACL almost identical to the adult knee.[12] However, the femoral attachment of the ACL differed in appearance from that of the adult in that it was more ribbon-like. Two main bundles were already detectable, but the bundles seemed to be more parallel when compared with the bundle orientation of the adult ACL.[12] This group concluded that the fact that the fetal knee had not been subjected to loading or twisting motion in extension could account for the different positioning of the ACL with regard to the adult knee.[12] The early manifestation of the ACL in the fetal knee joint suggests that the knee joint is early under the stabilization and guidance of the ACL. The fact that the cruciate ligaments are present at this early stage of development could lead to the assumption that they interact with the resulting shape of the femoral condyles and the tibial plateau.[10]

Gross Anatomy

The ACL is a band of dense connective tissue that connects the femur and the tibia. It is enveloped into the synovial membrane of the human knee joint, which by definition places the ligament intraarticular but extra-synovial.[9,10,13] The ligament originates at the medial side of the lateral femoral condyle and runs an oblique course through the intercondylar fossa distal–anterior–medial to the insertion at the medial tibial eminence. Due to its orientation within the knee joint, the ACL has been shown to be primary restraint to anterior tibial translation and secondary restraint to internal rotation of the weightbearing and non-weightbearing knee.[14-20]

The width of the ACL ranges from 7 mm to 12 mm.[21-23] The ligament fans out toward its insertion at the tibia and the narrowest diameter can be found in the midsubstance area of the ACL. Anderson and coworkers reported an oval shaped diameter of the midsubstance with an area of 36 mm^2 and 44

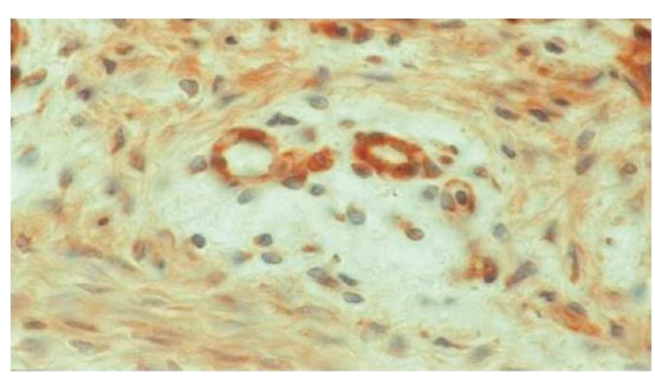

Figure 2 Vascular endothelial growth factor (VEGF) immunostaining, fetal ACL 22 weeks after gestation. The high expression of the angiogenic factor VEGF is largely downregulated after birth but will be re-expressed during the remodeling of autologous tendon grafts used for ACL reconstruction. Anti-VEGF antibody, ×260.

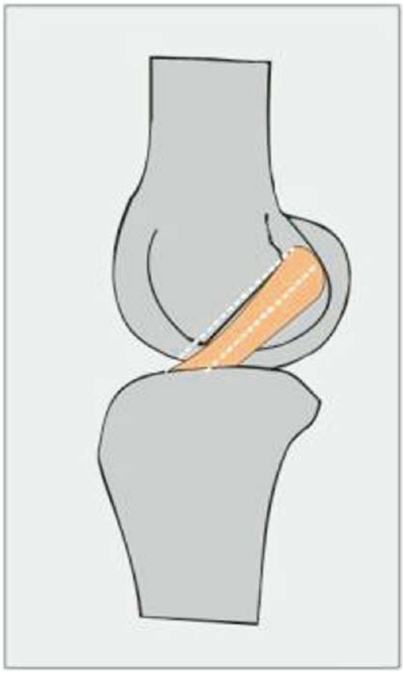

Figure 3 Because of the anatomical shape of the insertion areas at the femoral and tibial insertion site, anterior fibers of the ACL are able to bend around the anterior edge of the intercondylar notch. Common reconstruction techniques do not replicate the foot type insertion at the tibia. A straight graft (dotted lines) such as a bone–patellar tendon–bone or hamstring graft may impinge at the notch in knee positions close to extension.

mm^2 for females and males, respectively.[24] Harner and co-workers digitized the insertion areas of the ACL and reported that relative to the ligament midsubstance the tibial and femoral insertion of the ACL was more than 3.5 times larger.[25] The broad femoral and tibial insertion area with respect to the narrow diameter of the midsubstance makes selection of tunnel site placement more challenging because of the limited size of potential grafts.[25]

The axis of the long diameter of the ACL is tilted 26° ± 6° forward from the vertical.[13,22] During its course in the joint, the ligament seems to turn itself in a lateral spiral. This external rotation is app. 90° as the fibers approach the tibial surface. The twist of the fibers of the ACL is a result of the orientation of its bony attachments. The femoral attachment is oriented primarily in the longitudinal axis of the femur whereas the tibial attachment is in the anteroposterior axis of the tibia.[10]

The ACL tibial attachment fans out and forms a "foot" region. This allows the ACL to tuck under the roof of the intercondylar notch. In full extension the anterior fibers of the ACL turn around the anterior edge of the intercondylar notch (Fig. 3). This bending is considered as a "physiological impingement." This specific anatomy causes concern for ACL reconstruction since common grafts do not posses such a "foot"-type region. If a straight graft is inserted in the anterior part of the tibial ACL insertion it tends to impinge with the notch in slight degrees of flexion (Fig. 3). Notch impingement due to anterior tibial tunnel positions is a common cause for postoperative extensions block.

The topographical anatomy of the intercondylar fossa has been investigated for many reasons, including evaluation of the native ACL and identification of proposed reconstruction attachment sites, as well as for acute rupture of the native ACL and chronic impingement of the graft after ACL reconstruction. ACL surgery is normally performed with the knee in 90° of flexion. Therefore in the clinical literature the notch roof is considered to be superior, shallow, deep, and inferior (Fig. 4).

The intercondylar notch is wider in the posterior part and converges toward the anterior direction. It is well known that significant osteophyte formation and stenosis of the outlet of the anterior outlet of the intercondylar notch occur early in the ACL-deficient knee. In these cases, a notchplasty should be considered at ACL reconstruction. The width of the notch is reported to be smaller in females when compared with males.[26-32] This could be another factor in explaining the higher incidence of ACL injuries in female athletes besides

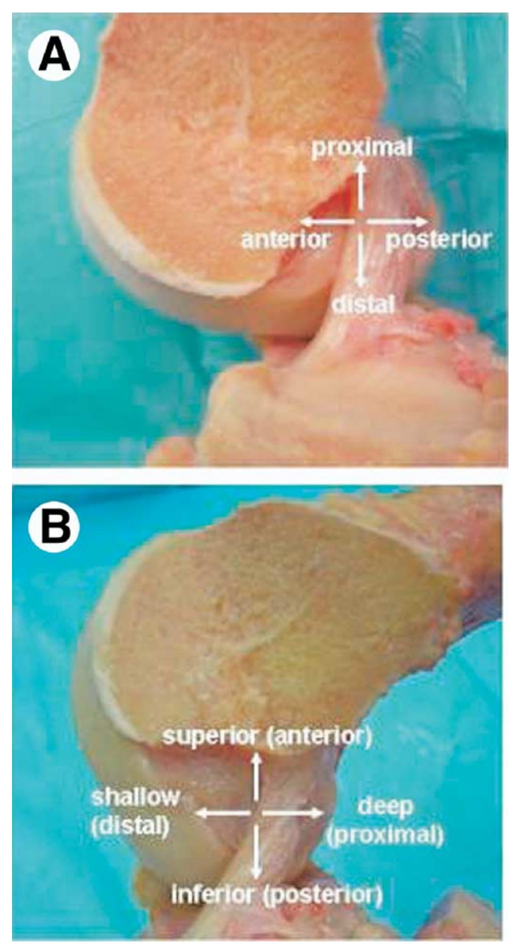

Figure 4 (A) Full extension, the medial femoral condyle is cut off to inspect the femoral attachment of the ACL. (B) 90° of flexion. Arthroscopic surgery is normally performed with the knee in 90° of flexion. In clinical literature the notch roof is considered to be superior (anatomic description: anterior), the anterior rim is considered as shallow, the posterior part is considered as deep, and the posterior part is considered as inferior.

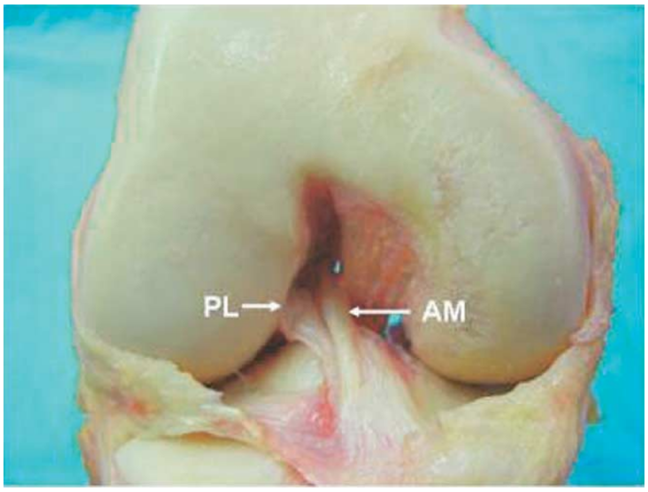

Figure 5 Right knee joint from anterior. The patellar tendon and the surrounding soft tissue have been removed to inspect the ACL. Note the 2 distinct bundles, the AM and PL bundles.

gender specific neuromuscular differences. The notch width index (NWI) is used for the ratio epicondylar width to notch width. Since patients with bilateral ACL rupture showed a smaller NWI, the risk of sustaining an ACL rupture could be higher with a smaller NWI.[26] The intercondylar fossa is shaped like a gothic arch and the roof of the fossa is well known as "Blumensaat's line," which can be seen on conventional lateral knee x-rays. The angle between the longitudinal axis of the femur and the notch roof (notch roof angle) varies between 23° and 60°.[33] Knees with a small notch roof angle are also known as "non forgiving knees."[33] In these knees the position of the tibial bone tunnel is rather critical to prevent graft impingement by the anterior rim of the intercondylar notch.[33]

Anteromedial (AM) and Posterolateral (PL) Bundle

It has long been realized the ACL does not function as a simple band of fibers with constant tension as the knee moves but the differentiation of the ACL; however, the differentiation of the ACL into different bundles is discussed controversial in the literature. Girgis and coworkers[34] divided the ACL into 2 bundles, namely the AM and PL bundle (Fig. 5). The termination of the bundles were chosen according to their tibial insertion with the fibers of the AM bundle originating in the most proximal part of the femoral origin and inserting at the AM tibial insertion. Fibers of the PL bundle originate distal at the femoral origin and are inserting on the PL part of the tibial insertion.[10,14,34] However, Odensten and Gilquist examined the ACL histologically and found no evidence to separate the ligament into 2 bundles.[22] Amis and Dawkins as well as other authors divided the ACL in an AM, intermediate, and PL bundle.[21] Even though there is disagreement on the actual anatomic division of the ACL, the general consensus appears to agree that the ACL has distinct functional bands, which vary the tension among the fibers in the ligament with different ranges of motion.

The differentiation of the ACL into 2 distinct bundles seems to be an oversimplification, but the 2 bundle description of the fibers of the ACL has widely been accepted as a basis for the understanding the function of the ACL. When the knee is extended, the PL bundle is tight and the AM bundle is moderately lax. As the knee is flexed, the femoral attachment of the ACL becomes a more horizontal orientation; causing the AM bundle to tighten and the PM bundle to loosen up. This concept has been confirmed by a biomechanical study performed by Amis and Dawkins.[21] This study has shown that the PL bundle is stretched in extension and the AM bundle in extension; but none of the ACL fibers behave isometric.[21] A recent study using a robotic/universal force moment sensor underlined the importance of the PL bundle.[35] This study has shown that the in situ forces of PL bundle in response to a 134 N anterior load are highest in full extension and decreased with increasing flexion. In addition, the study further demonstrated that the PL bundle plays a significant role in the stabilization of the knee against a combined rotatory load, which suggests the need for a more anatomical reconstruction designed to replicate 2 bundles of the ACL.[35]

Our own anatomical and in vivo studies have shown a great variance in size of the 2 bundles. In an in vivo study evaluating the PL bundle during arthroscopy, we were able to define the 2 bundles in all cases. However, in some cases the AM bundle was overlying the PL bundle and the PL bundle could only be seen by careful retraction of the AM using a probe (Fig. 6), which may explain why some orthopaedic surgeons are not aware of presence and insertion site of the PL bundle.

Length and diameter of the native ACL play an important role for choosing the type of graft and for the preparation of the graft in ACL reconstruction. Especially for some extracortical fixation techniques using linkage material, the intraarticular length of the native ACL may be important since it will determine the length of the graft that is available in the femoral and tibial tunnel. The length and orientation of the ACL fibers have been reported to change throughout passive flexion and extension as well as tibial internal and external rotation.[14,21-23,36,37] The length of the ACL fibers range from 22 mm to 41 mm with a mean of 32 mm.[21,23] However, these measurements are more for the AM bundle. Little is known about the intraarticular length of the PL bundle. Kummer and Yamamoto measured the intraarticular length of the PL bundle in 50 cadavers and reported a length of 17.8 mm.[36] Several studies have shown that the distances between origin and attachment of the ACL fibers vary with motion of the knee. According to the tensioning pattern, the distance for the AM bundle increases with flexion. Takai and coworkers reported an increase of 3.3 mm at 90° of knee flexion.[38] Hollis and coworkers showed a 3.6 mm greater distance for the AM bundle insertions at 90° of flexion.[39] The length of the PL bundle however, was decreased at 90° of flexion when compared with full extension by 1.5 mm and 7.1 in the study by Takai and coworkers[38] and Hollis and coworkers,[39] respectively. Amis and Dawkins reported that an internal tibial rotation lengthened the fibers more than external rotation,

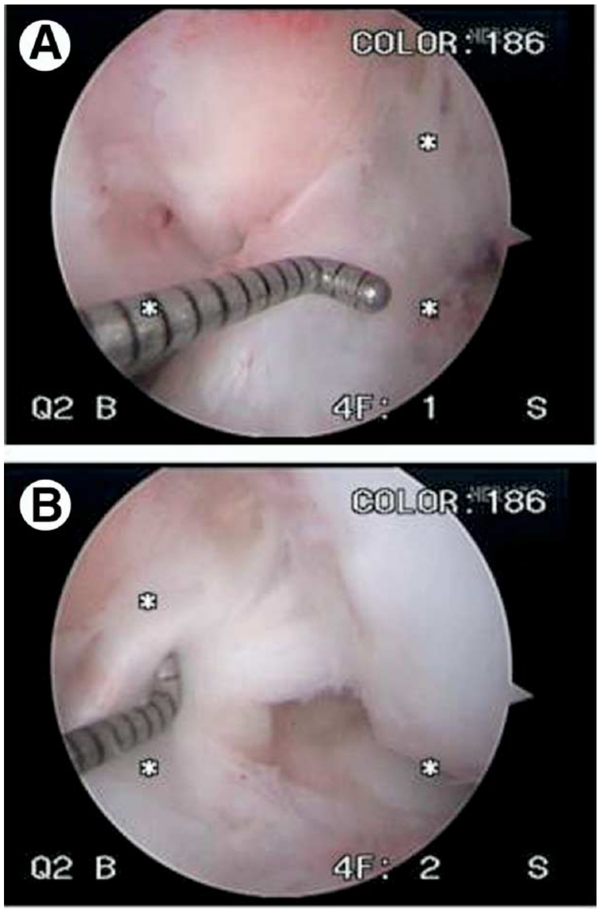

Figure 6 Arthroscopic view of a left knee through the anterolateral portal. (A) View of the AM bundle. The AM bundle is concealing the PM bundle. (B) View of the PM bundle. The bundle can be seen if the AM bundle is retraced with a probe.

which was most pronounced at 30° of flexion.[21] Recently, Zaffagnini and coworkers performed an original qualitative and quantitative analysis in cadaver knees and were able to demonstrate that internal rotation at 90 degree of knee flexion elongated the PL bundle by 2.7 (±1.7) mm.[37]

For ACL reconstruction and femoral tunnel placement it might be important that Hefzy and Grood demonstrated that fiber length is affected more by varying the femoral attachment.[40] Moving the tibial location had only a small effect; however anterior-posterior and proximal-distal variations at the femoral insertion site had strong effects on length patterns.[40]

Femoral Origin

The femoral origin of the ACL at the posterior part of the medial surface of the lateral femoral condyle has been described in several studies.[13,22,34] Girgis and coworkers described the femoral insertion as a segment of a circle with its anterior side straight and the posterior side convex.[34] Other authors using laser-digitizing methods found the insertion site to be more circular[25] or more oval with a mean length of 18 mm and a width of 11 mm.[22]

For the clinical practice, it seems important to appreciate the 3-dimensional shape of the ACL insertion that extends from the roof of the notch downwards along the cartilage contour to the inferior wall of the lateral femoral condyle. Additionally, when placing the femoral tunnel the surgeon should keep in mind the very posterior localization of the attachment site (Fig. 7). Anterior tunnel misplacement is a common pitfall in ACL surgery and a common cause of revision. A too anterior tunnel placement may result in instability and a flexion deficit (Fig. 7).[40,41] Because of the slightly convex nature of the lateral femoral condyle the arthroscopic visualization of the femoral origin of the ACL can be technically demanding. A better visualization may be possible by switching the scope to the medial portal when determining the entrance point for the femoral tunnels. Furthermore it is

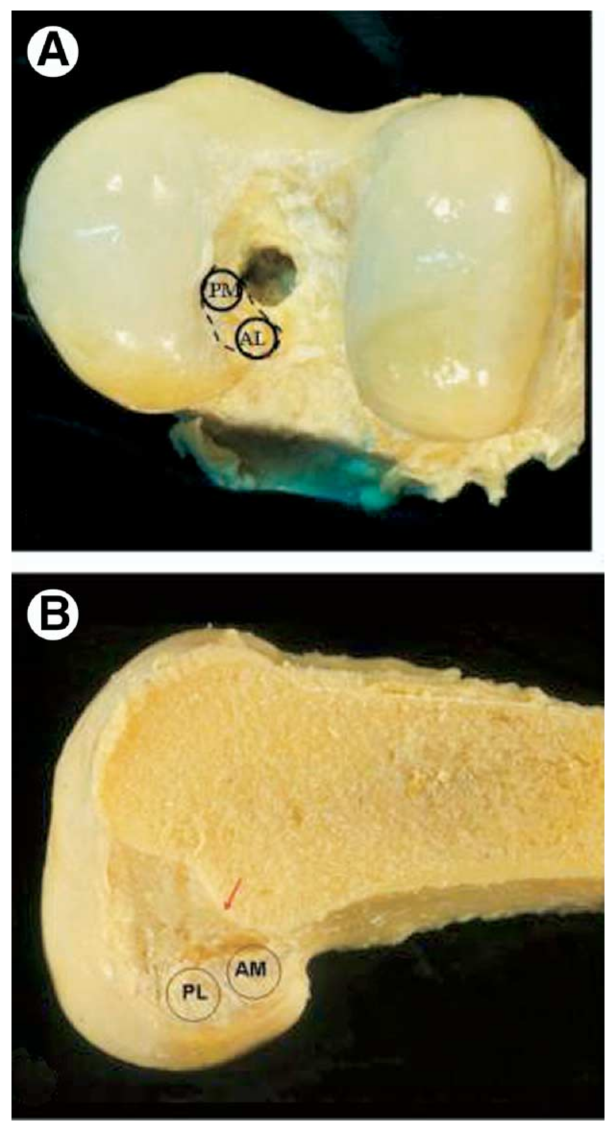

Figure 7 Human femur after ACL reconstruction, view from distal (A) and medial (B). (A) Wrong placement of the femoral tunnel. The entrance of the tunnel is too anterior when compared with the anatomical origin of the AM bundle. (B) An anterior tunnel misplacement could be due to a relative prominence that can be found 3 quarters of the way back on the roof to lateral border of the notch (arrow), which can be mistaken for the true over-the back position.

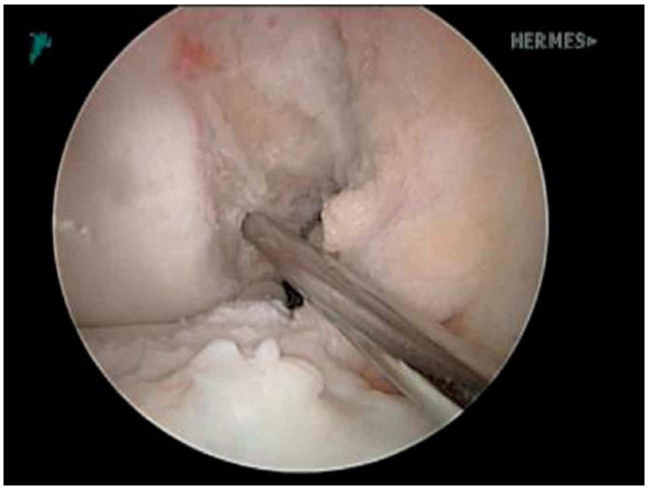

Figure 8 Right knee, arthroscopic view of the femoral insertion of the ACL through the scope in the anteromedial portal. The K-wire is inserted thorough an additional medial portal, close to the articular cartilage margin to locate the entrance of the tunnel for the PL bundle.

important to know that the ACL origin lies behind a small bony ridge, also known as "residents ridge," which could be the reason for an too anterior tunnel placement if this ridge is falsely considered to the over-the-top position.[42]

Bernard and Hertel described the quadrant method for defining the center of the femoral insertion site of the ACL on conventional x-rays.[43] These authors showed that the center of the ACL attachment on the lateral femur condyle can be located at 24.8% of the distance defined by the intersection of Blumensaat's line and the contour of the lateral femoral condyle on lateral x-rays and at 28.5% of the height of the lateral femoral condyle from Blumensaat's line. They concluded that by dividing the intercondylar fossa into quadrants, this point can be found inferior to the most superoposterior quadrant.[43]

To describe the ACL origin in the frontal plane, a circle can be drawn onto the notch in a clockwise fashion as proposed by the scientific committee of the European Society of sports Traumatology, Knee Surgery and Arthroscopy. The clock position has been criticized by basic researchers as well as clinicians since it cannot take the 3-dimensional characteristics of the insertion of the ACL on the medial surface of the lateral femoral condyle into consideration. However, it has been useful to describe tunnel positions on tunnel view x-rays, computed tomography scans, and magnetic resonance imaging scans.[44]

There is a high variability for the femoral origin of the AM and PL bundle. The AM bundle is located in the superior and posterior aspect of the femoral origin; the PM bundle origins in the anterior and inferior aspect. In basic research studies examining double bundle ACL reconstructions the AM tunnel has been placed in the 11-o'clock position and the PM tunnel in the 10 o'clock position. Own anatomical studies have shown that the origin of the PM bundle tends to be rather in the 9 o'clock position than in the 10 o'clock position.

Two clinical studies comment on the placement of the femoral PL bundle tunnel. Muneta and coworkers recommended placing the 2 femoral tunnels at the 12:30 position for the AM and 1:30 for the PL bundle, respectively.[45] However, our own anatomical findings are controversial to this description. In our anatomical studies we found the center of the PL bundle to be close to the posterior cartilage margin of the lateral femoral condyle. On the basis of these anatomical findings, we place our femoral tunnel for the PL bundle in anatomical ACL reconstructions using 2 femoral sockets quite differently than described by Muneta and coworkers or Rosenberg and coworkers previously (Fig. 8).[45,46]

Tibial Insertion

The insertion site for the ACL on the tibia is located in the area between the medial and lateral tibial spine (Fig. 9). Because of the fanning of the ligament, the insertion site is much larger than midsubstance and femoral attachment of the ligament. Harner and coworkers found the tibial insertion of the ACL to be approximately 120% of the femoral insertion site.[25] The insertion site is a broad oval area, approximately 11 mm diameter in the coronal plane and 17 mm in the sagittal plane.[10,13,34] The challenge for the correct tibial tunnel placement is related to the diameter of the graft with respect to the much larger insertion site.[25,33] In some specimens, the fibers of the AM bundle have been described to

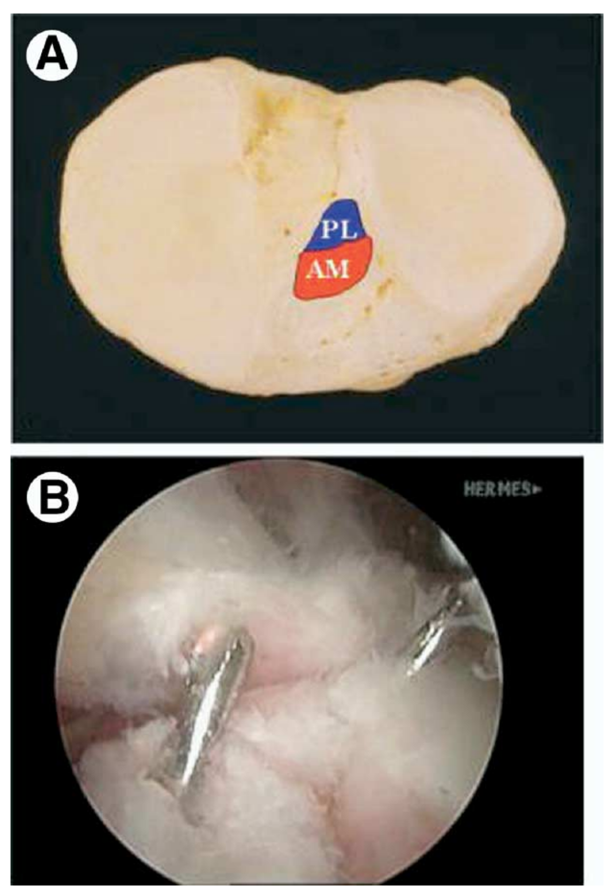

Figure 9 Tibial insertion site. (A) Anatomic specimen (left knee). (B) Arthroscopic view of the tibial insertion. The 2 K wires mark the positions for the tunnel in an anatomical ACL reconstruction.

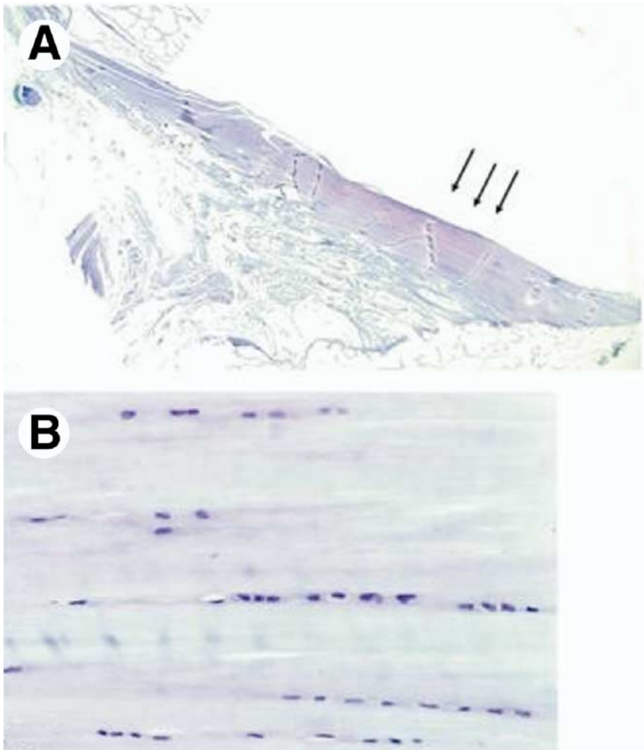

Figure 10 Toluidine blue stained histological section of the anterior part of the distal third of the ACL. (A) In the part where the ACL is in contact to the fossa ("physiological impingement") a metachromatic staining of the ACL can be found. (B) A close-up of this area reveals typical tenocytes as well as chondrocytes-like cells.

confluence with the lateral meniscus at its anterior insertion whereas the PL bundle can send fibers to the posterior attachment of the lateral meniscus.[34]

Stäubli and Rauschning performed cryosections in vitro and MR arthrography in vivo to provide guidelines for the placement of the tibial tunnel. From these findings, the authors concluded that the tunnel should be drilled at 44% of the tibial diameter posterior and parallel to the individual intercondylar roof inclination angle.[47] These results are in accordance with an earlier publication by Howell and coworkers[48] in which the center of tibial attachment is 7 mm lateral to the medial tibial spine.[22]

For the localization of the tibial attachment of the ACL, 2 different anatomical landmarks currently are in use. Specifically, some surgeons prefer to orientate themselves at the anterior edge of the PCL insertion. Several studies have shown that the distance between this point and the tibial ACL attachment is approximately 7 mm.[49,50] Other authors have criticized the tibial tunnel placement with respect to the PCL because the surgeon could probably tend to place the tibial tunnel too far posterior. These surgeons would place their tibial tunnel with respect to the anterior insertion of the lateral meniscus, which has been described to be aligned with the anteromedial aspect of the ACL insertion.[34]

Fine Structure

The ACL consists of soft connective tissues. The collagen fibrils are surrounded by connective tissue, which forms multiple fascicles within the ACL.[10,51] The major collagen of the ACL is type I collagen whereas the loose connective tissue consists of type III collagen.[10,51]

The cell bodies of the fibroblasts appear elongated.[10,14] In the anterior part of the distal third, the typical cell morphology is different when compared with the typical structure of ligaments. In full extension, this part of the ACL is in direct contact to the intercondylar fossa.[10] Histological sections of this area reveal typical tenocytes as well as chondrocytes-like cells (Fig. 10). Because of the direct contact of bone and ligament, the appearance of chondrocytes could be explained as a functional adaptation of the ligament to the occurring compressive stress which is caused by the "physiological impingement" between the ACL and the anterior rim of the intercondylar fossa.[10]

Microscopically, femoral origin and tibial insertion have the structure of a chondral apophyseal enthesis that consist of 4 layers (Fig. 11). The first layer is composed of the ligament

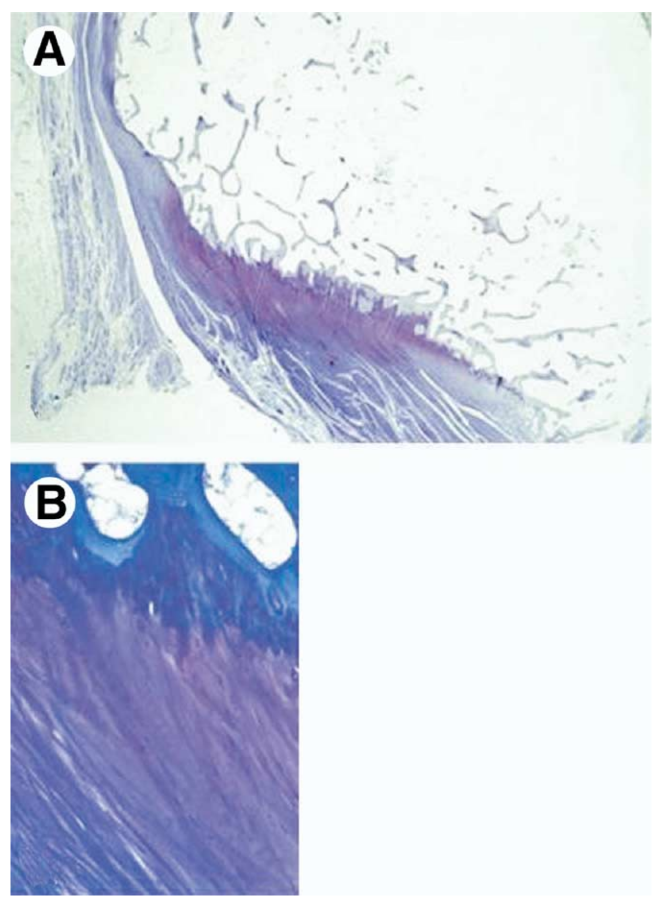

Figure 11 Toluidine blue stained histological sections of the femoral origin. (A) The femoral origin has the structure of a chondral apophyseal enthesis consisting of 4 layers. (B) Close up of the enthesis. The 4 layers can be described as ligament fibers, nonmineralized cartilage zone, mineralized cartilage zone, and subchondral bone plate.

Figure 12 Blood supply of the ACL. The distribution of the blood supply is not homogenous. Avascular areas can be found at the insertion sites and within the area of fibrocartilage-like cells.

fibers. Fibrocartilaginous cells aligned within the collagen bundles can be found in the second layer described as non-mineralized cartilage zone, whereas the third layer is the mineralized cartilage zone. The fibrocartilage is mineralized and inserts into the subchondral bone plate, which is the fourth layer (Fig. 11).[52] Because of this specific anatomy of the insertions, the ACL shows a transition zone from rigid bone to ligamentous tissue thereby allowing graduated change in stiffness and may prevent stress concentration at the attachment site.[10,13,14]

Histologic studies have shown that soft-tissue grafts with an extracortical fixation do not develop a chondral insertion. The insertion of soft-tissue grafts resembles to a fibrous insertion in which the fibrils of the graft insert directly to the bone. However, a recent study in sheep has shown that when the grafts are fixated close to the joint line a chondral insertion comparable to the normal ACL is restored.[53]

Blood Supply

The proximal part of the ACL is supplied by vessels from the middle genicular artery. Distally, the ligament is supplied by branches of the lateral and medial inferior geniculate artery.[26,54,55] Proximal and distal vessels support a synovial plexus from which small vessels run into the ligament and align longitudinally parallel to the collagen bundles. Using injection techniques as well as immunohistochemistry, avascular areas could be found at the insertion areas as well as in the part of the ACL where chondrocytes-like cells can be found (Fig. 12).[10] Because tissue with diminished blood supply shows a poor healing potential, it has been hypothesized that there could be a tendency toward worse healing of lesions of the ACL in these parts.[10]

Nerval Innervations

Most neural structures have been found in the subsynovial layer and near the insertions of the ACL,[9] however neurotracer studies have indicated that there are very few receptors in the ACL.[56] The receptors found are mainly Ruffini receptors in their function as stretch receptors and free nerve-endings as nociceptors.[56] These findings are in accordance with electromyographic studies which show that the receptors are predominantly responding when the knee is in extension. Releasing neuropeptides with vasoactive function, these nociceptors may play an important role in tissue homeostasis or in healing of grafts.[56] Adachi and coworkers found a positive correlation between the number of mechanoreceptors and the accuracy of joint position sense in the remaining ACL stump.[57] Therefore, the authors concluded that preserving ACL remnants during ACL reconstruction could contribute to proprioception.[57] In accordance to this, Reider and coworkers showed recently that reconstruction of a mechanical restraint (ACL graft) has a significantly positive impact on early and progressive improvement in proprioception of the injured knee.[58]

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