15 Anatomy of ACL Insertion: Ribbon

Robert Śmigielski and Urszula Zdanowicz

15.1 Femoral Insertion

Śmigielski et al. [7, 9] in his anatomical dissection of 111 fresh-frozen cadaveric knees (from 81 people) evaluated in detail the femoral insertion site of the anterior cruciate ligament (ACL). All degenerative knees (with fourth-degree chondromalacia) were excluded from the study. There were 45 males and 36 females. The mean age was 67 and mean BMI 22,6. After carefully removing the synovial membrane that covers the ACL, flat, "ribbonlike" appearance of the anterior cruciate ligament was clearly seen (Fig. 15.1). This flat appearance was also confirmed in MRI and CT scan as well as in histology evaluation.

This flat appearance was also noted in several previous papers.

In 1980, Welsh [10] describes that femoral ACL attachment "inserts into a broad flat area on the back of the lateral femoral condyle." It inserts "not as a distinct cord but is splayed over a broad flattened area."

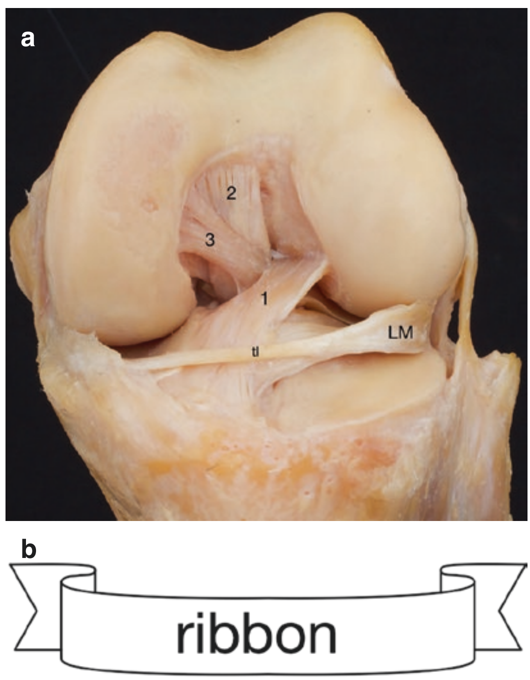

Fig. 15.1 (**a**) Cadaveric specimen of human left knee joint. (*1*) Anterior cruciate ligament (ACL). Notice: flat and wide, "ribbonlike" appearance of ACL. (*2*) Posterior cruciate ligament (PCL). (*3*) Anterior menisco-femoral ligament. *LM* lateral meniscus, *tl* transverse ligament. (**b**) Schema of "ribbon shape." Some authors also compare this shape of ACL to "lasagna," "pappardelle," "fettuccine" or "kishimen" pasta

R. Śmigielski, MD (✉)
Orthopaedic and Sport Traumatology Department, Carolina Medical Center,
Pory 78, Warsaw 02-757, Poland
e-mail: robert.smigielski@carolina.pl

U. Zdanowicz
Orthopaedic and Sport Traumatology Department, Carolina Medical Center,
Pory 78, Warsaw 02-757, Poland

McGowan Institute for Regenerative Medicine, University of Pittsburgh, Pittsburgh, PA, USA

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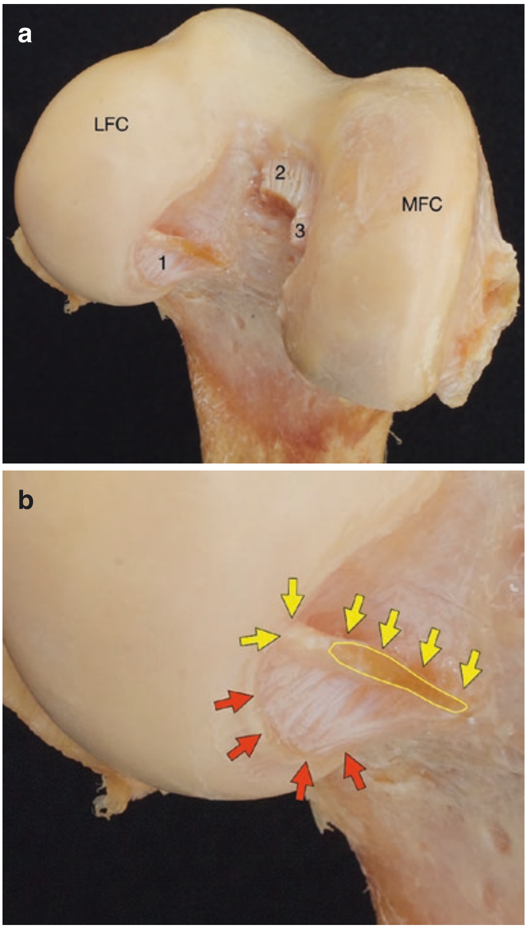

Fig. 15.2 (**a**) Cadaveric specimen of human right distal femur. *LFC* lateral femoral condyle, *MFC* medial femoral condyle. (*1*) ACL. (*2*) PCL. (*3*) Anterior menisco-femoral ligament. (**b**) Close look to femoral ACL attachment. Notice: Fanlike fibers marked with *red arrows*. Midsubstance fibers marked with *yellow arrows*. Own material

In 2013, Mochizuki et al. [4] published a paper in which he evaluates anatomical appearance of fanlike extension fibers at the femoral ACL attachment site in 28 cadaveric knees. He distinguished between direct and indirect insertion, based on histological appearance. Direct insertion (midsubstance fibers) has a transitional cartilaginous zone through which ACL fibers attach to the bone. That kind of insertion is typical for areas with great tension applied. The indirect insertion is created by fanlike extension fibers which are directly attached to the bone (Fig. 15.2a, b).

The attachment of midsubstance fibers of ACL is in exact continuity of the posterior femoral cortex [7, 9] (Fig. 15.3a–c). Knowing that relationship, the surgeon may double check the position of his femoral tunnel: arthroscopically and intraoperatively with X-ray C-arm. However, one may not talk about tunnel placement without a context of graft and fixation choice (Fig. 15.4a–c). For example, the use of BPTB graft or even a hamstring graft with interference screw fixation allows to "push" the graft to the side of the tunnel. Therefore, if the graft is supposed to arise from the place where midsubstance ACL fibers have their direct attachment, the center of tunnel drilled should be a little "higher" (more toward ventral side).

15.2 Midsubstance

Early studies by Arnoczky [2] and Welsh [10] describe the midsubstance of the ACL to have multifascicular structure. In his study, Welsh describes that the midsubstance of ACL turns 90°. He also points out that this is functionally of great importance, because whatever the position of the knee would be (extension or flexion), some portions of ligament remain functional and under tension. Welsh goes further and stated that even though ACL consists of two parts – anteromedial band and posterolateral band – that division would be oversimplification, because the ligament is not made up of two parts, but is a continuum of fibers with a broad insertion. This turning of the ligament and a broad flattening at the insertion means that ACL is truly isometric with actual lengthening or shortening of the ligament during knee movement, but rather tightening of different components within the ligament through different phases of range of motion.

In 1998, Amis et al. [1] also describes this twisting nature of midsubstance of ACL. The twist is unwounded as the knee extends and the fibers remain almost parallel in full extension (Fig. 15.5).

In 2006, in times when nobody really considered ACL to be literally flat, Mochizuki et al. [5]

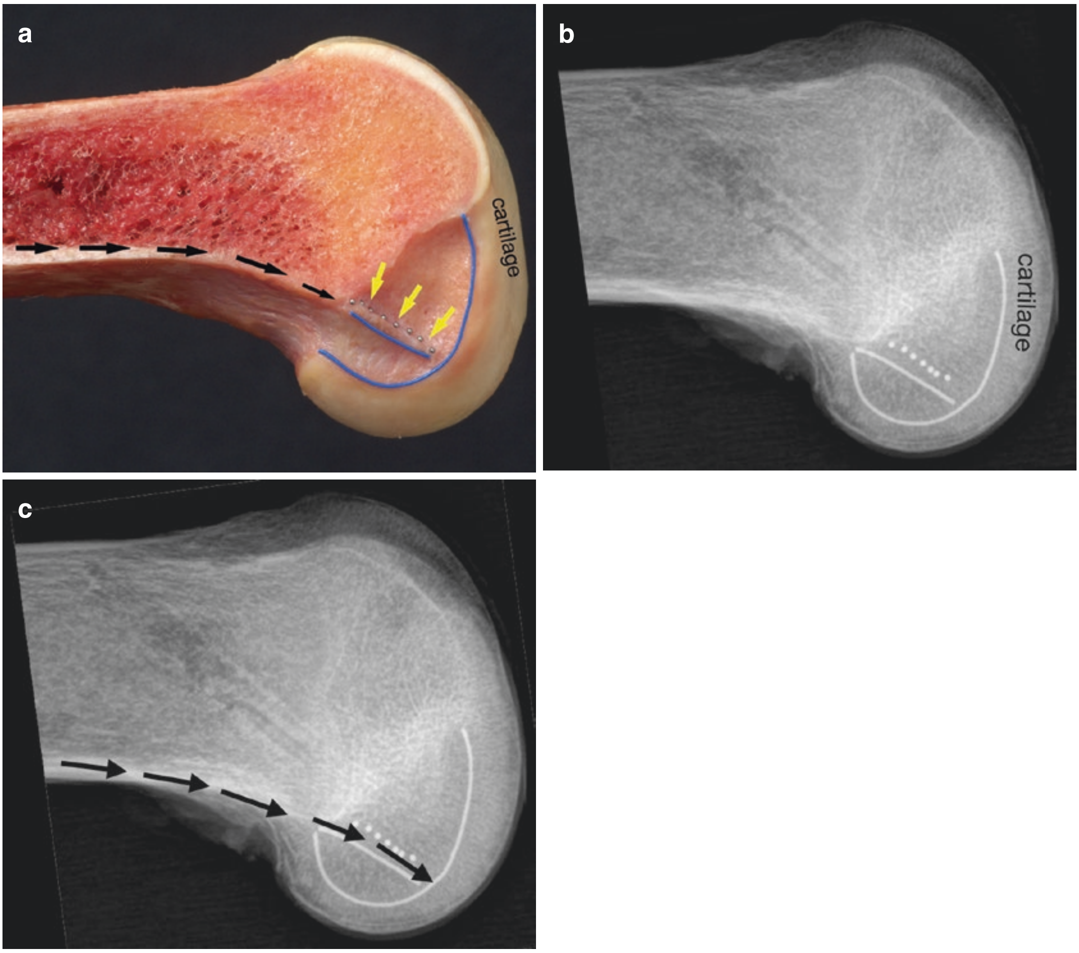

Fig. 15.3 (**a**) Cadaveric specimen of the left human distal femur. Medial view on the lateral femoral condyle, after removing (longitudinal cut) of medial femoral condyle. Posterior femoral cortex is marked with *black arrows*. The direct insertion of midsubstance fibers of ACL (marked with *yellow arrows*) is in line with posterior femoral cortex. *Blue suture marks* the borderline of articular cartilage and dorsal borderline of direct ACL insertion. *Silver balls mark* the ventral borderline of direct ACL insertion. (**b**, **c**) Same specimen, lateral X-ray. Notice relationship of direct midsubstance ACL fibers to posterior femoral cortex. Intraoperative X-ray allows for better control of correct localization of tunnel placement

published a paper describing an anatomical femoral tunnel placement of "double-bundle" ACL. In this paper, he noticed that "the configuration of the natural ACL midsubstance was not oval, but rather flat, looking like 'lasagna' about 15 mm in length and about 5 mm in width after removing of the surface membrane." Also while carefully evaluating his picture documentation of the cadaver study, this flat ACL appearance is clearly visible.

15.3 Tibial Insertion

The anterior cruciate ligament arise from the tibia forming a "C" shape (Fig. 15.6a, b). It was first presented by Śmigielski in 2012 during ACL Study Group meeting ("The Ribbon Concept of the Anterior Cruciate Ligament"; Presentation at the ACL Study Group Meeting 2012, Jackson Hole, Wyoming, USA) and later confirmed by other researchers [6–8]. Researchers also describe

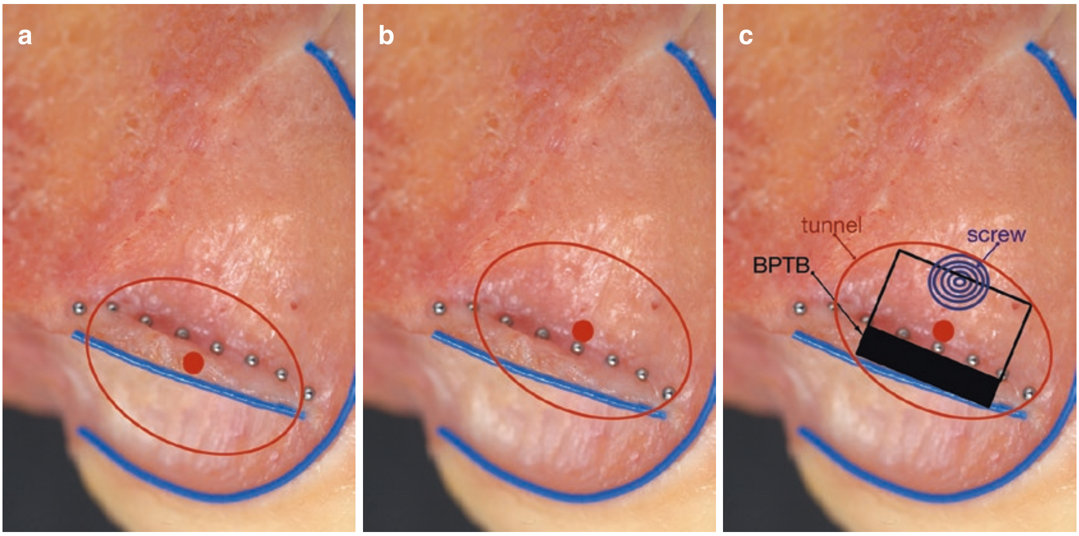

Fig. 15.4 Close look on ACL femoral insertion site. While choosing a perfect spot to drill your tunnel, you must think about your choice of graft and the fixation. In case of hamstring graft and Endo-button fixation, (**a**) your graft will arise from more or less the center of your tunnel, so the center should be at the level of the direct attachment of ACL midsubstance fibers. On the other hand, in cases of BPTB graft or a hamstring graft with an interference screw fixation, the screw will push your graft to the side of your tunnel (**b**, **c**), so your tunnel center should be little above the direct midsubstance ACL attachment

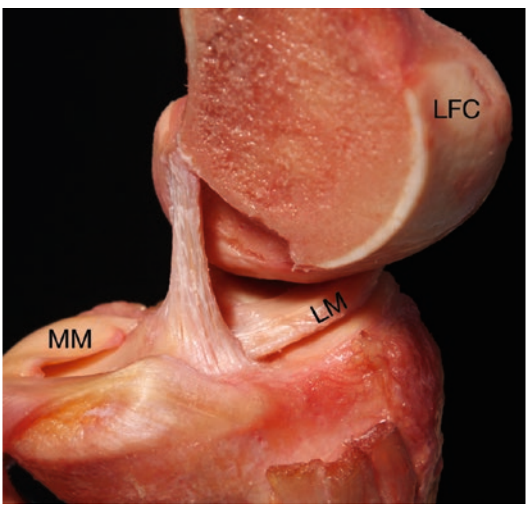

Fig. 15.5 Cadaveric specimen of the left knee joint. Medial femoral condyle is removed. *LFC* lateral femoral condyle, *LM* lateral meniscus, *MM* medial meniscus. Notice the way ACL is positioned in sagittal plane in knee extension. Compare the horizontal ACL arrangement with Fig. 15.1 (knee in flexion). Thanks to that phenomenon even a narrow intercondylar notch has enough space for ACL

the distal part of ACL as of appearance of a "duck-foot".

One of the most interesting findings is the relationship between ACL tibial attachment and anterior horn of lateral meniscus. With the knee in flexion, as observed during arthroscopy. ACL passes backward, "laying over," covering the anterior horn of the lateral meniscus. That information has very practical consequences for surgeons drilling tibial tunnels for ACL reconstruction – to have in mind topographic anatomy and try not to destroy lateral meniscus.

Śmigielski et al. also observed three different types of the ACL tibial insertion: 67 % of specimens had a classical C-shaped tibial insertion site, 24 % J-shaped, and 9 % Cc-shaped (as presented by Śmigielski in 2012 during ACL Study Group, not published data).

The histological cross section of ACL tibial attachment allows for additional better understanding of ACL anatomy in this area. Oka et al. [6] stated that, in contrast to previous findings, functional midsubstance ACL fibers arise from the most posterior part of the "duck-foot," in a flat, "C-shaped" way. The most anterior part of the tibial ACL insertion is bordered by a bony anterior ridge and the most medial by the medial tibial spine. No posterolateral fibers nor ACL bundles have been found histologically (Fig. 15.7).

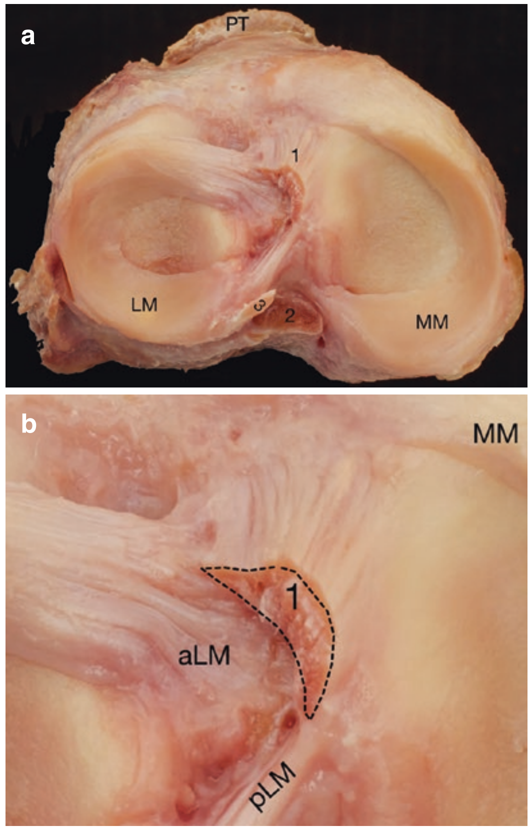

Fig. 15.6 (**a**) Cadaveric specimen of the left knee joint, femur removed. *1* ACL. *2* PCL. *3* anterior menisco-fibular ligament. *LM* lateral meniscus, *MM* medial meniscus, *PT* patellar tendon. (**b**) Closer look at tibial ACL attachment. *aLM* anterior horn of lateral meniscus, *pLM* posterior horn of lateral meniscus. Notice the way ACL arise from tibia forming a "C" shape and the way it surrounds anterior horn of lateral meniscus

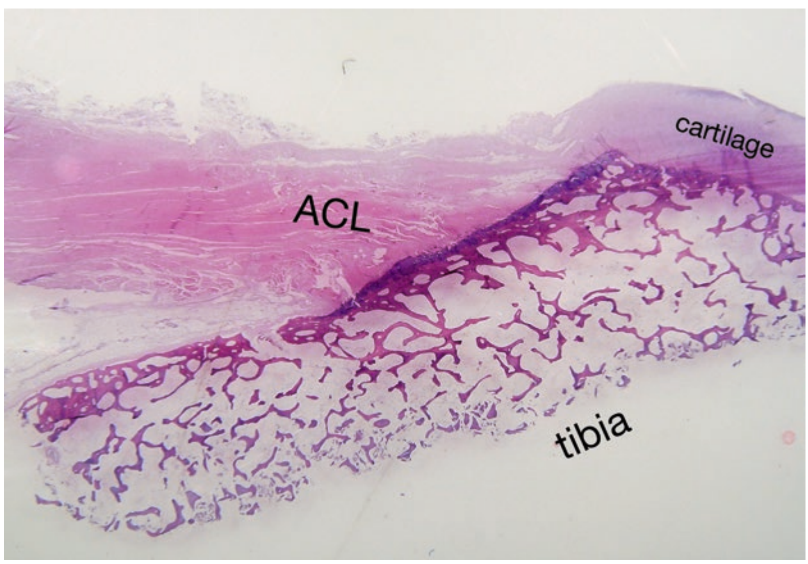

Fig. 15.7 Histology of the tibial ACL insertion (light microscopy, H&E stain)

15.4 Summary

In summary, it is the best to quote after John Feagin [3]: "Understand, respect and restore anatomy as much as possible."

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