Flat ACL anatomy: fact no fiction

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In 1836 Wilhelm and Eduard Weber published their detailed work on the anatomy and physiology of the lower extremity (Fig. 1) [25]. The anterior cruciate ligament (ACL) was shown to be flat in extension, twisted in flexion and aligned with the posterior femoral cortex. Nearly 100 years later (but also 100 years ago!), exactly in 1921 two French anatomists named Testut and Jacob described the flat ACL midsubstance and the close relationship between the anterior horn of the lateral meniscus and the tibial ACL insertion (Fig. 2) [24]. They beautifully showed that the bony insertion of the anterior root of the lateral meniscus was

just posterior to the ACL insertion in the area intercondylaris anterior. No bundles have been drawn.

At the beginning of the “modern” era of ACL surgery, such small details may not have played an important role for the orthopaedic society. Surgeons in their nature were fascinated by solving exciting technical issues like open and arthroscopic approach, transtibial and single-incision technique, bone tunnel placement and graft choice. So our ancestor’s art was forgotten.

In 1938 Ivar Palmer was the first to describe bundles of the ACL and to perform an ACL reconstruction using a “double-bundle” technique [17]. Later Girgis et al. [8] divided the ACL into two functional parts: a smaller anteromedial band and a larger posterolateral band. This description was then used as a basis to understand the function of the different fascicles of the ACL [4, 18]. Whereas some authors found three anatomical bundles [2, 14], others only described a single flat continuum of fascicles without any bundle structure [3, 16, 26]. Inspired by anatomical reports, the ACL “double-bundle” reconstruction was refined by innovative surgeons like Mott [12], Zaricznyj [28] and Muneta et al. [13].

The last 10 years experienced a “double-bundle boom” which was driven by many surgeons and scientists around the globe [1, 5–7, 15, 20, 21, 27]. In an intention to better understand the ACL and to optimize surgical results, the anatomy and surgery was revisited. There was a strong interest to investigate the “double-bundle” structure with its anteromedial (AM) and posterolateral (PL) bundles and its insertion sites to support the surgical double-bundle concept. More than 600 articles have been published in PubMed related to the topic in recent years.

Simultaneously in 2006, the flat midsubstance and flat femoral ACL insertion was described by Mochizuki et al. [11]: “The configuration of the natural ACL midsubstance is not oval, but rather flat, looking like ‘lasagne’ about 15 mm in length and about 5 mm in width after removal of the surface

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Fig. 1 Drawings of Wilhelm and Eduard Weber, 1836 [25]

Fig. 2 Findings of Testut and Jacob, 1921 [24], showing flat midsubstance of ACL and tibial relationship between ACL and lateral Meniscus

membrane. The femoral insertion was found to be very similar to the flat midsubstance configuration after the ligament surface membrane was removed from the attachment site". In 2010 Iwahashi et al. [9] reconfirmed above findings and divided the femoral ACL insertion into "direct" and "indirect" ones. Sasaki et al. [19] found a 4-layered structure of the direct insertion, and again Mochizuki et al. [10] pointed out that it "is difficult to reconstruct the natural" (indirect) "fan-like extension fibres by creating a tunnel although the midsubstance fibres can be reconstructed by such procedure". In

contrast to dissections from Europe and USA, none of these 4 groups did describe any ACL bundles.

It was at the ACL study group meeting 2012 in Jackson Hole when Robert Smigielski surprised the ACL specialists by stating that the "ACL is a ribbon". His group had just reconfirmed the Japanese findings of the flat midsubstance and femoral direct insertion of the ACL by artful anatomical dissections in 111 fresh-frozen cadaver knees [23]. They also rediscovered the "lost treasure" of the tibial relationship between ACL and lateral meniscus described by Testut and Jacob in 1921.

Smigielski investigated the insertion of the ACL midsubstance to the tibia and found a "C-shape" alignment of the midsubstance fibres anterior and along the medial tibial spine (ACL study group meeting 2012 in Jackson Hole). This finding was reconfirmed macroscopically in 2014 by Siebold et al. [22] using magnifying lenses and by histological investigations in 2015 (accepted for publication in *Knee Surg Sports Traumatol Arthrosc*). Like the Japanese, both European groups did not find any ACL bundles. To adapt the terminology, the authors suggested to use the term "ACL fibres" for anatomical descriptions and the term "ACL bundles" only in the surgical context of ACL "double-bundle" reconstruction [22, 23]. Like on the drawing from Testut and Jacob [24], both groups could not find any tibial posterolateral inserting ACL fibres [22]. Therefore Siebold et al. [22, 23] proposed to change the term "posterolateral (PL)" ACL fibres into "posteromedial (PM)" fibres according to the tibial insertion site. Above anatomical findings are published in this KSSTA issue.

What may be the implementations to achieve better clinical results after ACL reconstruction? Further investigations in young cadavers may be wise to reconfirm the flat ACL anatomy in the population between 20 and 30 years. We may also aim for a flat “ribbon-like” reconstruction to mimic the flat ACL anatomy. For the moment, this may be best achieved with a flat patella tendon graft, a flat quadriceps tendon graft or a flat DB ACL reconstruction. As latter is very difficult, our group is currently working on an easier flat reconstruction with a flat semitendinosus tendon. Finally, for ACL reconstruction using a “double-bundle” technique, it may be recommended to change the tibial “PL” bone tunnel position into a “PM” one [22].

We never know, if something becomes better when we change it.

But we know very well, that we have to change if we want to improve.

Dante (1265–1321)

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