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Original Article

Flat anatomy of ACL and “ribbon like” ACL reconstruction

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Abstract

Recent anatomical studies show clear evidence that the anterior cruciate ligament (ACL) has a ribbon like structure from its femoral origin to its tibial attachment. The femoral bony origin of the ACL is half-moon like and the tibial attachment is duck-foot like. On the femoral side the flat midsubstance raise from its origin in a straight line and on the tibial side in a “C”-shaped way. Twisting of the flat ACL from extension to flexion gives the impression of separate bundles. However, no bundles could be found in recent studies. Based on above findings this article introduce a new technique for a flat ACL reconstruction. It was developed to reproduce the native “ribbon like” morphology of the ACL, with a rectangular femoral- and a C-shaped tibial socket.

Keywords: Ribbon-like ACL reconstruction, Flat ACL anatomy, Anterior cruciate ligament, Flat graft, C-shape

Introduction

A thorough understanding of the ACL anatomy is essential to create an anatomical ACL reconstruction, that will be able to reproduce the kinematics of the knee joint and mimic its biomechanical properties.

The surgical techniques to replicate the native anatomy of the ACL were always driven by the contemporary understanding of its anatomy and biomechanical function. The idea of creating a double-bundle construct was already implemented in 1938 by Palmar[1] to mimic the anatomical structure of the ACL. In the study of Girgis et al[2] 1975 the ACL was divided in bundles (anteromedial and posterolateral bundle) in an order to address their biomechanical properties. For many years, that has been the basis for ACL reconstruction. Some authors even reported a triple bundle anatomy[3,4] others detected a flat continuous structure of the ACL without a bundle distinction[5-7] (Figure 1).

Femoral insertion and midsubstance

In 2006 Mochizuki et al[8], reported that the natural ACL midsubstance is “lasagna” like, about 15 mm in length and 5 mm in width. They also observed the uniform composition of the ligament, without evidence of separate bundles microscopically.

Iwahashi et al[9] in 2010, reported on the direct insertion and the indirect femoral insertion of ACL fibres. On the direct insertion, dense collagen fibres attach to the bone, whereas the indirect insertion is formed by a coarse fibrous region. In 2014, Mochizuki et al[10] reconfirmed previous findings and pointed out that it is difficult to reconstruct the native indirect fan-like extension fibres with a tunnel, because the direct insertion is longer and too flat for an oval bone tunnel.

In 2014 Smigielski et al[11] reported a flat, ribbon like appearance of the ligament from its femoral origin to the tibia attachment in their anatomical dissections of 111 cadaveric knees. The mean width 2 mm from the femoral origin was found to be 16 mm (12.7-18.1), the mean thickness 3.5 mm (2.0-4.8) and the mean cross-sectional area 56.6 mm^2. Previous studies already pointed out, that the femoral origin is the extension to the posterior femoral cortex and aligned just posterior to the lateral intercondylar ridge[12-14].

The senior authors (C.F., R.S., R.S.) have a conflict of interest (consultant for Medacta).

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Figure 1. Anatomical dissection of the left femoral attachment of ACL with flat midsubstance and direct insertion in extension of posterior femoral cortex along lateral intercondylar ridge, half-moon-like bony footprint with indirect attachment (blue) and over the top position (red) (Siebold 2008).

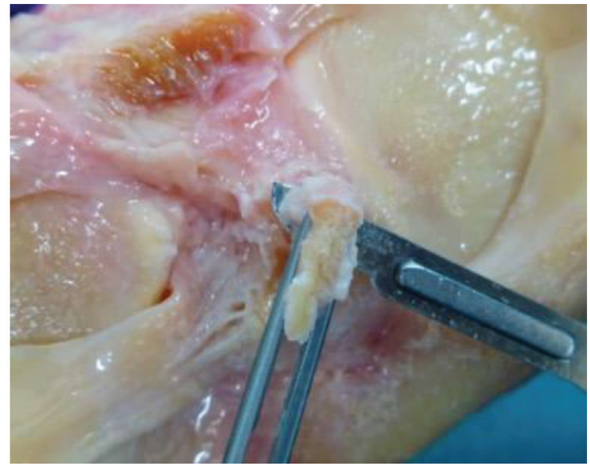

Figure 2. Anatomical dissection of the flat midsubstance ACL fibres, C-shaped tibial attachment and bony duck-foot-like insertion. The bony roots of anterior and posterior horn of lateral meniscus form a ring with ACL insertion (Siebold 2015).

There was no histological evidence that bundles exist, but rather a collection of individual fascicles. The twist of the flat ligament makes the impression of bundles[11,15]. The cadaveric study of Noailles et al[16] in 2017 investigated the effect of ACL torsion in 90° of flexion. In their study of 42 knees they found a twist of the ACL fibres of 83.6° in 90° of flexion, which reconfirms the double-bundle effect of the flat ACL midsubstance described by the senior authors.

Tibial insertion

In 1983 Arnoczky et al[6] found the tibial insertion of the ACL to be in a fossa in front and lateral to the anterior tibial spine. This insertion passes beneath the transverse ligament and a few fascicles of anterior ACL blend with the anterior attachment of lateral meniscus, as well as some posterior fascicles blend with its posterior attachment.

In 2014 Smigielski et al.[17] reported the ribbon concept of the ACL with its tibial "C" shaped ACL insertion. The authors found three main different types of insertion: 67% had the C-shape, 24% had a J-shape and 9% a Cc-shape. From this "C"-shaped insertion the fibres form the flat midsubstance of the ACL. No posterolateral and no central inserting fibres were detected and no separate bundles could be macroscopically identified.

These findings were reconfirmed by Siebold et al[15] using magnifying lenses in a macroscopic and histological study[18]. The "C" shaped attachment of the midsubstance fibres and the fan-like anteriorly extended fibres form the duck-foot-like tibial bony attachment. The "C"-shape" insertion had a mean length of 12.6 mm and thickness of 3.3 mm. The posterior ACL fibres of the tibial attachment were inserting medially along the medial tibial spine. The authors proposed to abandon the name "PL" bundle and to use the term "PM fibres" instead. Siebold et al[15] also described that the ACL forms a ring with the roots of the lateral meniscus as pointed out by Arnoczky et al[6]. These findings were reconfirmed recently by several authors[19-22] (Figures 1,2).

"Ribbon-like" ACL reconstruction: Surgical technique

Recently the senior authors (C.F., R.S., R.S.) developed a new technique, that creates a rectangular bony socket at the femoral origin and a "C-shaped" one at the tibial attachment to better replicate the anatomy with a flat ACL graft.

Patient positioning

The patient is positioned supine in a surgical table, while allowing the knee to flex from 0° to 120° degrees, and a thigh tourniquet is applied.

Graft preparation

The flat ACL reconstruction can be performed using a semitendinosus graft after a simple conversion to a flat graft. This can be done by splitting its round part longitudinally with a knife. The tendon is unrolled with the use of a forceps to flatten it (Figures 3,4). The biomechanical studies of Domnick et al[2]3 have shown no difference between the prepared flat graft and the original round graft in a porcine flexor tendon model.

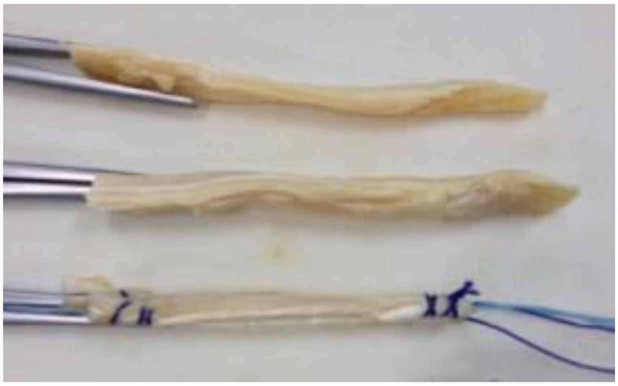

Figure 3. Flat ACL grafts. From button to top: flat tripled semitendinosus tendon, flat natural patellar tendon, flat harvested quadriceps tendon (Siebold, Smigielski, Fink).

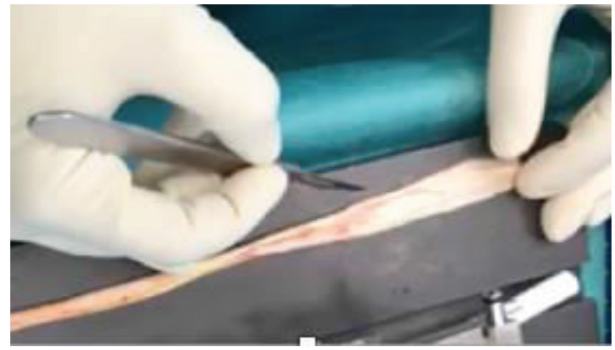

Figure 4. Creating a flat graft from a round semitendinosus graft (Fink).

The graft is then triple- or quadruple-folded and stitched to both ends with two No2 Fiberwire sutures in a Krackow fashion. The length of the graft should be minimally 6-7 cm. A quadriceps- or patella tendon graft can also be used directly without requiring the process of conversion to a flat graft.

Femoral tunnel

After visualization of the femoral footprint the knee is flexed to 110°. A microfracture awl is used to mark the central position of the femoral tunnel attachment, which is the middle of the total length of the direct straight ACL attachment. It is just posterior to the lateral intercondylar ridge and in continuity to the posterior femoral cortex. The correct positioning may easily be checked with a C-arm and arthroscopically through the anteromedial portal. With the use of the special femoral targeting device the central guidewire is inserted, thereafter the ventral and dorsal ones.

The central guidewire is overdrilled with a 4.5 mm drill through the proximal femoral cortex, whereas the two other guidewires are overdrilled for about 25 mm. A dilator according to the size of the graft is then inserted to finalize the size of the femoral tunnel.

A minimum of 15 mm of graft should be inserted into the femoral tunnel (Figure 5).

Figure 5. Rectangular femoral slot in extension of posterior femoral cortex just posterior to intercondylar ridge created in a left cadaveric knee (Siebold, Smigielski, Fink).

Tibial tunnel

The C-shaped targeting device for the tibial insertion is placed directly on the tibial C-shaped footprint of the ACL along the anterior border of the ACL attachment and along the medial tibial spine. A central guidewire to stabilize the device is inserted and two 4.5 mm drills are used to overdrill the outer two parts of the tunnel. A cannulated drill is used to overdrill the central guidewire. The final size of the tibial

Figure 6. C-shaped tibial slot around bony attachment of anterior horn of lateral meniscus created in a right cadaveric knee (Siebold, Smigielski, Fink).

C-shaped slot is achieved by a dilator according to the size of the graft.

The graft is inserted transtibial using the passing suture while keeping the knee close to extension to accomplish the twist during flexion.

The femoral fixation is established with a flipped button, whereas the tibial fixation is achieved with a new designed locking button in full extension (Figure 6).

Postoperative rehabilitation

Full active range of motion is encouraged postoperatively. Partial weight bearing (10 kg) for the first week and increased weight-bearing thereafter on crutches. Physiotherapy is recommended 2 times a week with proprioception exercises and closed-chain kinetic exercises for at least 6 weeks. Sport specific exercises can be recommenced after 5 months and return to sports after 8-12 months.

Discussion

For many years the anatomy of the ACL was described to have at least two bundles, the anteromedial and posterolateral one. The division was based on anatomical studies and used for biomechanical models[2,3,24,25]. In an attempt to improve clinical results the latest technique developed was to reconstruct the AM and PL bundles separately in a double bundle technique[26-29].

However, 2012-2015 the ribbon anatomy of the ACL was introduced[11,15], which may again change the surgical approach to ACL reconstruction. The introduced new technique of flat ACL reconstruction was designed to reproduce the flat anatomy, as well as its rectangular flat femoral origin and its C-shaped tibial insertion. On the femoral side, a rectangular socket is created at the ACL direct femoral origin just behind bifurcate ridge. On the tibial side, a C-shaped socket is created and the flat graft that is introduced transtibial can know simulate the physiological twist s during flexion.

This new approach to ACL reconstruction may have several biomechanical and biological advantages[30]. The anatomic C-shaped socket and flat structure of the graft enable an adequate anterior positioning while sparing the anterior attachment of the lateral meniscus. This avoids damage to the anterior bony insertion of the lateral meniscus and does reduce the risk of notch impingement. The flat graft and positioning of the tibial and femoral sockets help to recreate the normal torsion of the ACL in different degrees of knee flexion, along with its biomechanical implications. Furthermore, the flat configuration of the graft along with the rectangular shape of the sockets leads to a significantly higher bone to tendon contact with positive influence for graft integration and revascularization.

This technique represents a better approximation of the current knowledge of the ACL anatomy, is theoretically better and may anatomically more correct compared to current techniques. The clinical superiority has yet to be found. Clinical and biomechanical investigations have to confirm the theoretical advantages. It will be interesting to assess, if the new approach to ACL reconstruction can reduce the rerupture rate and better prevent the development of knee osteoarthritis.

Conclusion

Recent anatomical studies show clear evidence that the ACL has a ribbon like structure from its femoral origin to its tibial attachment. It has no defined anatomical bundles, but rather a collection of multiple individual fascicles. No PL or central fibres have been found, the posterior fibres are aligned along the medial tibial spine and should therefore be named PM fibres. In an attempt to better reconstruct the flat anatomy, a technique utilizing a flat hamstring graft, a C-shaped tibial and rectangular femoral socket was introduced. Even though this technique represents a better approximation of the ACL anatomy, clinical trials have to show its superiority over current techniques.

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