Anatomical anterior cruciate ligament reconstruction with a flat graft using a new tunnel creation technique

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Abstract: Anterior cruciate ligament (ACL) reconstruction is well established in a single bundle or double bundle technique using hamstrings, quadriceps tendon or patellar tendon. Based on new anatomical findings from the authors about flat ACL and c-shaped tibial insertion, a novel concept was developed to reconstruct the ACL in a more anatomical way. This article describes the new technique of flat ACL reconstruction with graft preparation and creation of flat femoral and tibial bone slits.

Keywords: Flat ACL; reconstruction; M-ARS; slit; direct femoral attachment; C-shaped tibial attachment

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Introduction

Motivated by the development of double bundle anterior cruciate ligament (ACL) reconstruction the interest in ACL anatomy led to the discovery of its flat femoral direct insertion and flat intraligamentous structure (1-4). The picture was completed by the anatomical description of Smigielski *et al.* (5). According to his findings (5-7) and those of others (3,8-10) the whole intraligamentous ACL appears to be flat, "ribbon-like" after removal of the synovial membrane. Smigielski *et al.* also rediscovered the tibial relationship between the C-shaped tibial attachment of the ACL and the lateral meniscus described by Testut und Jacob in 1921 (7).

By placing the graft in round Single Bundle (SB) bone tunnels the structure and composition of the direct insertion site is not reproduced. The principle of the new introduced "Medacta Anatomic Ribbon Surgery" (M-ARS) (Medacta International, Switzerland) technique is to create rectangular bone slits that resemble more closely the original flat ACL insertions on the femur and tibia to allow for a flat ACL reconstruction.

Biomechanical *in vivo* studies found that a flat graft alignment (as approximated DB ACL reconstruction) is advantageous in restoring rotational kinematics and stability compared to SB, when referenced to the healthy contralateral knee (11,12). Comparable kinematics to a native ACL could also be shown in ACL reconstruction using rectangular bone slits (13-15).

The new M-ARS technique could also potentially provide interesting biological benefits. As the contact area of a flat ACL graft is about 3 times greater in relation to its volume compared to a round one, the formation of Sharpey-like fibers as well as the vascularization can take place on a larger area. This may reduce central necrosis as described in the early graft healing phase (16) due to a reduced distance for diffusion.

The biomechanical and biological aims of the new ACL reconstruction technique are:

(I) Reconstruction of a straight rectangular bone slit for the femoral insertion;
(II) Reconstruction of a curved c-shaped tibial bone slit with preservation of the anterior horn of the lateral meniscus and the possibility of a more anterior (anatomical) position without notch impingement;

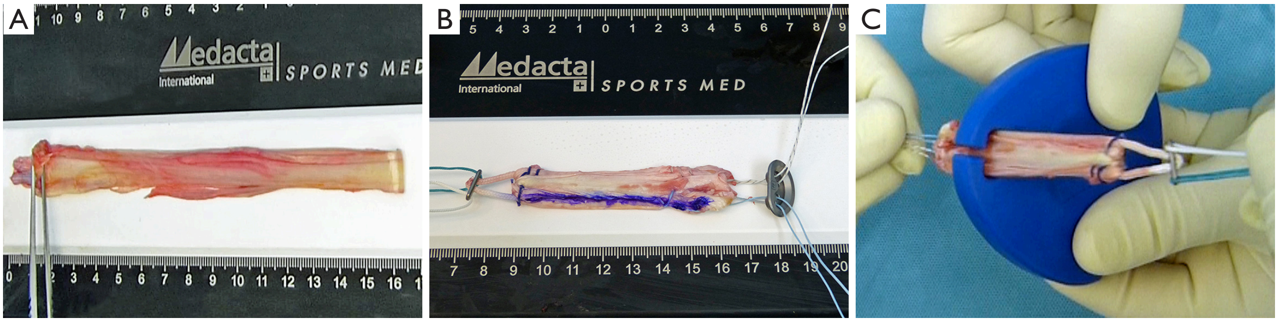

Figure 1 Graft preparation of Semitendinosus tendon. (A) Flattened and 2-fold Semi-T; (B) complete graft with proximal loop-button, flat quadrupled Semi-T graft, distal fixation button; (C) sizing (S/M/L) of flat quadrupled Semi-T graft.

(III) Use of a flat tendon graft which better fits in the notch without reducing total graft volume and resembling the native ACL with different fiber recruitment under tension throughout the range of motion;

(IV) Increased interface for tendon to bone healing with potentially improved or accelerated revascularization and tendon to bone healing.

Technique

Graft harvesting

Hamstring tendon or Quadriceps tendon (QT) are ideal for this flat M-ARS ACL reconstruction and may be used according to surgeons' preference.

Steps for graft preparation Semitendinosus tendon

(I) A length of 26 cm for a 4-fold Semitendinosus tendon (Semi-T) graft is needed.

(II) The tendon is cleaned from muscle tissue and is placed with the muscular side upwards on the preparation board. Starting from the proximal (muscular) end, the tendon is split with a knife towards the round distal end (pes anserinus). Then the tendon is flattened with a forceps to create an equal flat dimension from end to end (*Figure 1A*).

(III) The flat tendon is folded in the middle to create a 2-fold graft. For proximal fixation it is folded a second time over the loop of a (adjustable/flexible) suture button to create a 4-fold graft (*Figure 1B*).

(IV) If using a fixed femoral loop button, it must be chosen at the appropriate length to fit the femoral bone slit length. An easier way is to use an adjustable/flexible loop button. At least 15 mm of the flat graft should be inserted into the femoral (and tibial) slit. The length of the femoral tunnel should be marked on the graft.

(V) For distal fixation the tendinous end of the graft is prepared using an interlocking suturing technique (Krackow-stitch) with two No. 2 non-absorbable sutures, but without the sutures in the mid part. Then the distal sutures are thread through the tibial fixation button such that the concavity of the button looks to the lateral graft side (*Figure 1B*).

(VI) The size of the graft should be measured to define the final dimensions of the bone slits with the flat measuring device (S-small, M-medium, L-large) (*Figure 1C*).

Quadriceps tendon

QT may be harvested in a conventional open technique or with a minimal invasive technique using special harvesting instrumentation (17). The graft should have a thickness of about 4.5 mm, a width of 10–12 mm and a length of a minimum of 6.5–7 cm. Over the patella the periosteal strip of about 2 cm of the QT is carefully elevated and then cut (17).

Graft preparation Quad tendon

(I) The distal end of the graft (periosteum) (*Figure 2A*), which will become the femoral graft end, is folded over a suture that is removed after preparation and kept in place with a Lahey-goiter grasping forceps.

(II) Krackow-stitch sutures (*Figure 2B*) are placed on each side of the graft using non-absorbable sutures size 2. The stitches should be done in the outer 3 mm of the graft and the sutures should go back in the mid part of the graft using a simple spiral seem to get pulling strands in every portion of the proximal graft edge.

(III) Putting tension on all sutures shows a slight C-shape form of the proximal graft end and either the concavity or convexity should be marked as lateral or medial, respectively, for insertion.

(IV) The tendinous end of the graft, which will become the tibial end of the implanted graft, is prepared similar to Semi-T (*Figure 2C*).

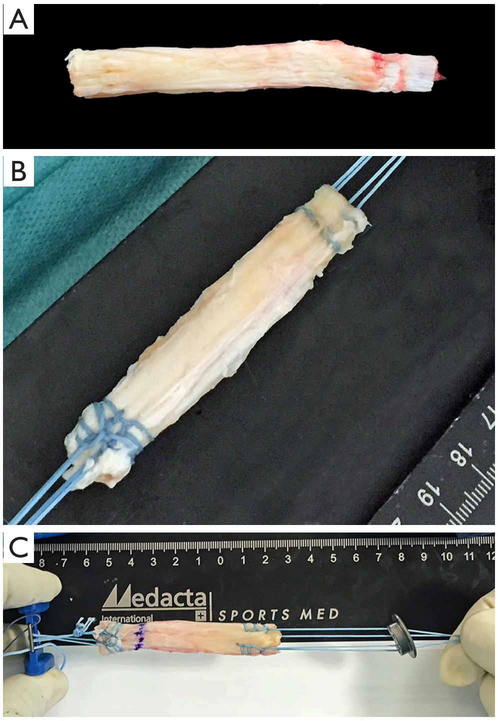

Figure 2 Graft preparation of Quadriceps tendon. (A) Flat harvested Q-tendon with periostal flap from patella; (B) proximal and distal armed flat Q-tendon; (C) flat Q-tendon with proximal loop button and tibial fixation device.

Femoral slit

(I) The ACL remnants are removed keeping the femoral attachment and the C-shaped tibial one (5).

(II) In 110° of flexion, a central guide wire (with a laser mark is drilled into the mid portion of the native femoral ACL insertion using a medial portal technique. The entry point is before marked with a microfracture ale after measuring the length of the attachment with a ruler. The central wire is introduced until the laser mark is flush with the femoral condyle and the position is double-checked from the medial portal. Now the tunnel length is measured with an outside-in measurement device from extra-articular.

(III) The femoral aimer is inserted into the joint and over the central guide wire using the central hole. Its orientation should be in line with the ACL attachment, which is approximately horizontal in 110° of knee flexion (4) (*Figure 3A*).

(IV) The anterior and posterior guide wires are drilled through the two peripheral holes of the femoral aimer, approximately 25–30 mm deep.

(V) The femoral aimer is removed and the peripheral two

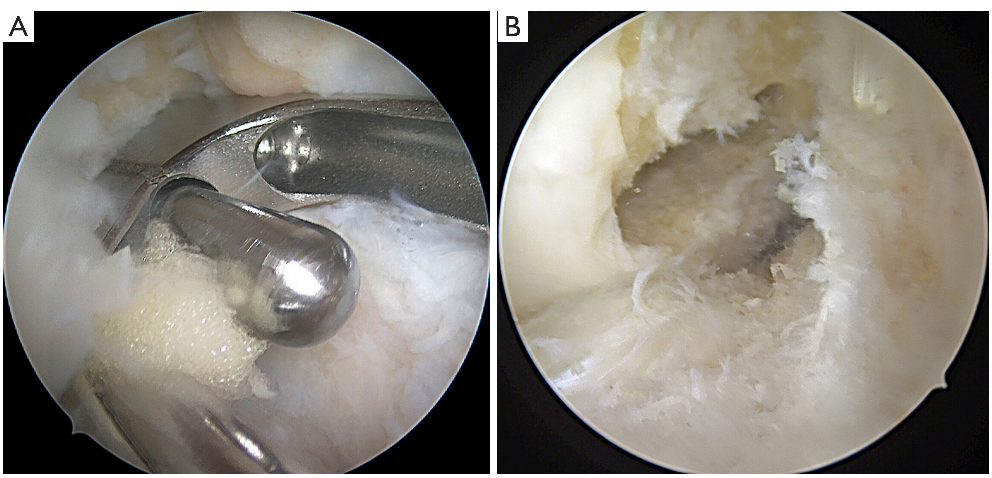

Figure 3 Arthroscopic creation of femoral slit. (A) Femoral aimer with central K-wire in position in direct ACL attachment site; (B) femoral straight slit after dilatation at direct ACL insertion.

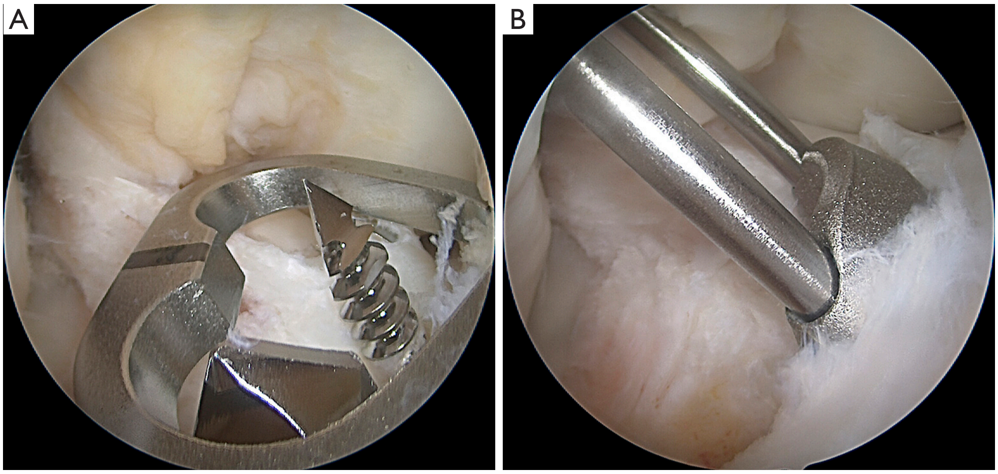

Figure 4 Creation of tibial c-shaped slit. (A) Tibial aimer in place with central K-wire and anterior 4.5 mm drill; (B) tibial dilatator with K-wires for save tibial dilatation.

wires are over-drilled with a 4.5 mm drill to a depth of 25–30 mm depending on the length of the central femoral tunnel without over-drilling the lateral cortex. The central guide wire is over-drilled through the lateral cortex with the 4.5 mm drill and is left in place.

(VI) A femoral dilator matching the graft size (S, M, L) is inserted over the central guide wire and tapped in to a depth of 25–30 mm. The resulting slit should be 10 mm deeper than the length of the graft in the femoral slit to allow the femoral fixation button to flip (*Figure 3B*).

Tibial slit

(I) The tibial aimer is chosen according to the side (r/l) and size of the graft (S, M, L). The threaded central k-wire is inserted into the tip hole of the bullet and is inserted into the tibial aimer.

(II) The aimer is inserted through the medial portal with the knee in 90° of flexion and placed around the anterior horn of the lateral meniscus and with reference to the ACL remnant. The threaded central k-wire is drilled into the joint (*Figure 4A*).

(III) First the shorter 4.5 mm drill bit is drilled through the anterior hole of the tibial aimer until just breaking the joint cortex and left in place (*Figure 4A*). Then the longer 4.5 mm drill bit is drilled through the posterior hole in a similar way. Both 4.5 mm drills and the aimer is removed leaving the threaded central k-wire.

(IV) It is now overdrilled by the cannulated 4.5 mm drill. Then everything is removed.

(V) The C-shape slit is finally prepared with the special dilatator using the two blunt guide pins in the anterior and posterior tibial 4.5 mm tunnel (*Figure 4B*). The size of the dilatator should be chosen according to S/M/L and it should be oriented with its concavity to the lateral meniscus. The distal part of the c-shaped slit should be dilated with the large dilator for perfect fit of the tibial fixation button.

Graft insertion

(I) The graft is pulled into position from distal to proximal through the tibial slit in the usual way. Correct orientation within the tibial tunnel is with the concavity looking laterally (*Figure 5A*).

(II) Once the graft emerges from the proximal tibial tunnel into the joint, the knee should be extended to get proper torque of the graft. Alternatively, the proximal end of the graft should be twisted for proper anatomical tibial-to-femoral fiber alignment (AM to AM, PM to PM) before pulling it into the femoral bone slit and before flipping of the femoral button is performed (*Figure 5A*).

(III) Finally, the knee is cycled to condition the graft and tibial fixation is performed with the tibial fixation button close to extension (*Figure 5B*).

Postoperative care

The patient is mobilized with partial weight-bearing

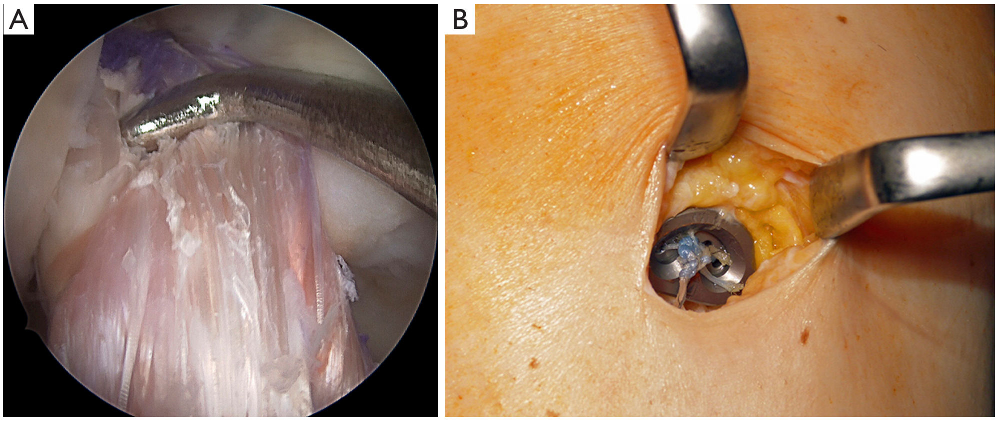

Figure 5 Graft passage and fixation. (A) Introduction of flat 4-fold Semi-T graft into the joint with 90° anatomical twist; (B) tibial suture button in place.

(15–20 kg) for 1–2 week, followed by full weight-bearing. Free range of motion is started directly postoperatively. Physical therapy is recommended 2–3 times per week.

Discussion

A new concept of single bundle ACL reconstruction is presented using either a Semi-T- or quadriceps tendon graft. The flat intratendinous alignment of the graft appears to be close to the native ACL anatomy (5-7). As any ACL surgery the new M-ARS ACL reconstruction technique has some pearls and pitfalls as well as some advantages and disadvantages compared to the conventional technique.

Our conventional technique for ACL reconstruction is to use drills to create bone tunnels for graft insertion. However, neither the femoral nor the tibial anatomical insertion sites are round—in contrast—flat and C-shaped tunnels respectively may offer obvious and potential advantages.

On the femoral side the creation of a flat slit mimics the direct attachment of the ACL and the introduction of a flat graft resembles the native intraligamentous "ribbon-like" ACL, changing its fiber orientation according to different flexion angles without overstuffing the notch.

The native tibial insertion site has been shown to be C- (67%) or J-shaped (24%) (5), which can be achieved most closely with the C-shaped slit in the tibia. The C-shaped slit around the root of the anterior horn of the lateral meniscus potentially avoids laceration of the lateral meniscus compared to conventional round tunnel placement (18-20).

In addition, the increased graft -bone contact area of a flat ACL graft in a bone slit compared to a round graft with similar cross-sectional area may provide a biological advantage leading to accelerated ingrowth and probably less central graft necrosis. The flat graft appearance may also present biomechanical advantages similar to ACL double bundle reconstruction or rectangular bone tunnels (13-15,21-24).

Conclusions

A new concept of single bundle ACL reconstruction appears to be close to the native ACL anatomy. As any ACL surgery, the new M-ARS ACL reconstruction technique has advantages and disadvantages. However early clinical experiences of the new technique are very promising with little risk for complications. Controlled clinical trials have to be conducted to evaluate whether the new technique leads to better mid-term to long-term results and could be beneficial for patients.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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