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TECHNICAL NOTE

Biologically enhanced ACL reconstruction

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Summary Biological integration of the tendon graft is a crucial prerequisite for successful ACL reconstruction. Histological studies showed that the human ACL remnants contain a cellular capacity for healing potential. The goal of this technical note is to describe an ACL reconstruction technique, using ACL remnants as a biological sleeve for the graft. In case of complete ACL rupture with a large remnant, the tibial tunnel was performed inside and through the ACL tibial stump by careful sequential drilling. Femoral tunnel placement was performed by an outside-in technique. The hamstring graft was kept attached to the tibia and routed through the ACL remnant to the femur. The aim of this technique is the preservation of the biological and mechanical properties of the ACL remnant. In order to preserve large remnants resulting in greater graft coverage, the best period to perform this reconstruction is during the first weeks after the injury.
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Introduction

Despite continuous improvements in ACL reconstruction, subsequent graft ruptures still remain an issue with a frequency ranging from 3 to 10% [1,2]. Shelbourne et al. [1] and Salmon et al. [2] hypothesized that return to strenuous activity and graft weakness are responsible for early graft failure. Therefore optimizing the biological integration and hence the strength of the ACL graft is now an area of great interest. The beneficial role of preserving the ACL remnant has already been demonstrated for ACL augmentation pro-

cedures in isolated AM or PL bundle ruptures [3—7]. Studies on scar patterns in ACL tears revealed that the ACL remnant induces a mechanical restraint to anterior tibial translation [8—10]. Beyond the potential mechanical advantage of this augmentation procedure, histology of human ACL remnants revealed their healing potential, especially due to an intact vascular support by the synovial sheath [11—13]. Furthermore, mechanoreceptors of the preserved ACL remnant may improve recovery of the joint positioning sense as suggested by Ochi et al., Adachi et al. and Lee et al. [14—16]. Based on these findings, it could be beneficial to develop a more biological technique for the reconstruction of complete ACL tears keeping the cellular and neurovascular capital of the ACL remnant [17,18]. The goal of this technique is to achieve an anatomic reconstruction of the ACL with preservation of the whole ACL remnant.

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Surgical technique

Patient selection

In patients consulting our unit for knee trauma with rapid swelling and disability, diagnosis of ACL rupture is made by clinical evaluation including Lachmann test, pivot shift and anterior laxity measurement by Rolimeter (Aircast, Summit, NJ). A positive Lachmann test with a firm end-point and a mean side-to-side instrumented laxity of 3 to 6 mm may suggest a partial ACL tear [7] or the presence of a large tibial remnant. MRI is examined to identify the rupture, rule out concomitant injuries and evaluate the remaining ACL stump: a large tibial remnant, generally encountered during the first weeks after injury, leans us towards a biologically enhanced ACL reconstruction.

Arthroscopic exploration

The type of ACL reconstruction depends on the initial arthroscopic exploration including complete articular assessment and meticulous inspection of the ACL lesion. The scar pattern and the size of the ligament remnant are analysed; thus, the complete or incomplete nature of the ACL tear is verified. By placing the knee in the figure-of-four position, the ACL is observed from its femoral to its tibial insertion [19]. In case of a partial ACL tear, selective AM or PL reconstruction is performed as described previously [4—7]. When the two bundles are detached from their femoral insertion, a single bundle reconstruction is carried out trying to preserve as much as possible the ACL stump. In chronic ruptures with a short, retracted tibial remnant a standard single bundle ACL reconstruction using a 10-mm wide patellar or quadriceps tendon graft is performed.

Graft harvesting

Our chosen graft for reconstruction of the ACL with preservation of its intraarticular remnant is the semitendinosus tendon. The goal is to obtain a graft with a diameter of 7 to 8 mm. This can be achieved with a unique doubled or tripled semitendinosus graft. A 2-cm oblique incision according to the Langer's lines is made on the medial side of the anterior tibial tuberosity. The graft is harvested using an open-ended tendon stripper in order to preserve its tibial insertion to further improve fixation. It is prepared after the bony tunnel drilling so its length can be adjusted accordingly.

Femoral and tibial tunnels

The knee must be at 90° of flexion to visualize the femoral insertion site of the ACL. The femoral ACL insertion is minimally debrided. Notchplasty should be avoided in order to keep the ACL femoral footprint. The femoral tunnel is drilled using a similar outside-in technique as described previously [20]. The femoral guide is hooked on the proximal border of the lateral femoral condyle placing the guide wire 7 mm distal to it in a very posterior location (Fig. 1). The intraarticular position of the guide wire and its relation to the anatomical footprint is then checked through the anteromedial portal. The tunnel diameter is equal to the graft size. It is drilled through a small skin incision on the lateral condyle.

The tibial ACL stump is inspected. If fixed to the PCL or a non-anatomic site on the femoral condyle, it is carefully mobilized preserving its entire synovial cover and tibial attachment. The tibial drill guide is then positioned in the centre of the anatomic ACL stump (Fig. 2) and the tunnel is drilled carefully under arthroscopic control in millimeter increments from 5 mm to at least the diameter of the graft. Care is taken to stay always inside the ACL stump and to preserve the synovial sleeve. Perforation of the tibial intercondylar eminence has to be done at low speed under visual control and must be stopped immediately after entering the joint in order to avoid any mechanical or heat induced damage to the ACL stump. The interior of the synovial sleeve is then debrided by a 3.5-mm shaver to avoid overpacking of the intercondylar notch and a consequent extension deficit.

Graft passage and fixation

The graft is routed from the tibia through the remaining ACL stump to the femur. Tibial fixation is performed first, using a 28-mm resorbable interference screw of the same diameter as the tunnel. The graft is then tensioned on the femoral side after several flexion-extension cycles. Graft fixation is classically done around 20 to 40° of knee flexion. A 23-mm interference screw of the same diameter as the tunnel is inserted in the femoral tunnel in an ''outside-in'' manner through the lateral incision to avoid damaging the graft at its intraarticular outlet. Once the graft is secured, it lies inside the intact ACL stump with circular synovial coverage of its major part. In some fresh ACL tears, the tibial remnant is very soft and might slip down to the tibial insertion of the graft causing a soft tissue impingement with the intercondylar notch. In these rare cases, the synovial sheet is secured to the proximal part of the graft by a single resorbable stitch. Graft impingement is ruled out by full knee extension under arthroscopic control.

Rehabilitation

Rehabilitation protocol is the same as for standard ACL reconstruction [21]. Running is authorized after 3 months and pivot sports after 6 months.

Results

Out of 438 ACL reconstructions performed in 2009, 43 (10%) had biologically enhanced ACL reconstruction as described above. Standard ACL reconstruction was carried out in 312 cases (71%), selective reconstruction of the PL or AM bundle in 26 (6%) cases and 57 (13%) were revision cases. Early follow-up examination showed no difference compared to standard reconstruction techniques concerning ROM, Lachmann test, Pivot shift and side-to-side instrumented laxity. No subsequent graft failure was identified till now.

On postoperative MRI scans at 3 months after surgery, the graft appears in low signal intensity and is easily dis-
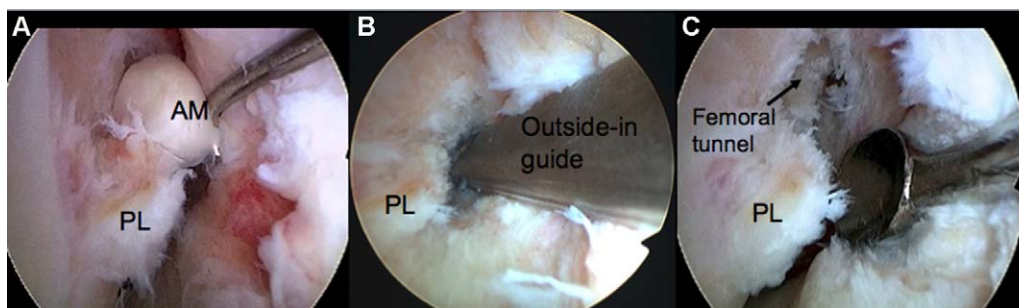
Figure 1   A. An acute ACL tear with AM and PL bundle remnants at the femoral ACL insertion site. B. The femoral outside-in guide with its target pin positioned in front of the anatomical footprint of the AM bundle. C. Femoral tunnel positioned in the proximal area of the ACL footprint.

tinguishable from the ACL stump which appears anterior to the graft with higher signal intensity. At 6 months, the graft signal intensity has increased and becomes similar to the ACL remnant suggesting an advanced remodeling process (Fig. 3).

Discussion

Many technical issues of ACL reconstruction have been resolved but subsequent graft rupture is still a problem with a rate ranging from 3 to 10% [1,2]. In a recent study, Shelbourne et al. [1] found 4 to 10% of subsequent graft rupture depending on age and gender in 1415 ACL reconstructions with patella tendon autograft. As did Salmon et al. [2], he attributed this to high activity level in young patients and graft weakness. Graft revascularisation and synovialisation are known to be crucial for both consolidation of the tendon graft and for graft strength [22,23]. The initial strength

and fixation of the graft could be responsible for early failure but does not explain late graft ruptures [24]. Therefore, lack of biological graft integration could be responsible for this failure.

Histologic examination of human ACL remnants demonstrate a cellular capacity for healing with an intact vascular support provided by the synovial layer [12,13,18]. In-vitro studies have demonstrated the intrinsic healing potential of the human ACL and the ability of cultured ACL fibroblasts to synthesize collagen [25]. Studies on partial ACL tears or surgically augmented complete tears in sheep and goats demonstrated the healing capacity of the native ACL [26—28]. As Lee et al. [17] described, preserving the ACL stump ensures not only its anatomical placement but could also promote its further healing and postoperative proprioception. One can postulate that the tendon graft serves as a biological scaffold for synovialisation and healing of the ACL as advocated by Murray and Spector [29]. Improved clinical results have been reported for patients with extensive graft
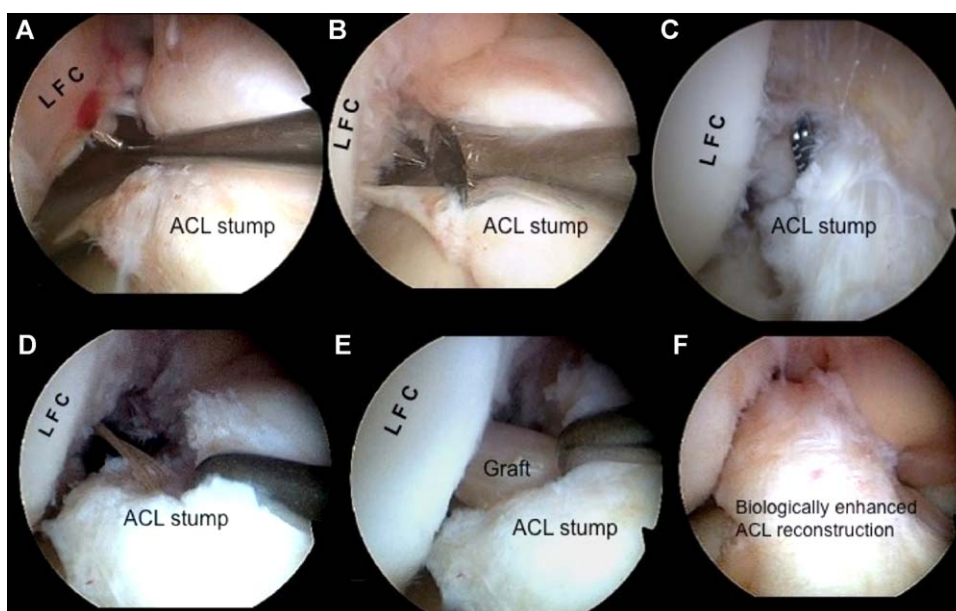

Figure 2   A. The ACL tear with an important ACL stump. B. Guide wire in the femoral ACL footprint. C. The shaver is introduced through the tibial tunnel and through the ACL stump. D. Traction wire through the femoral tunnel, the ACL stump and the tibial tunnel. E. The semitendinosus graft routed through the stump. F. Final reconstruction with the graft covered by the synovial sleeve of the stump.
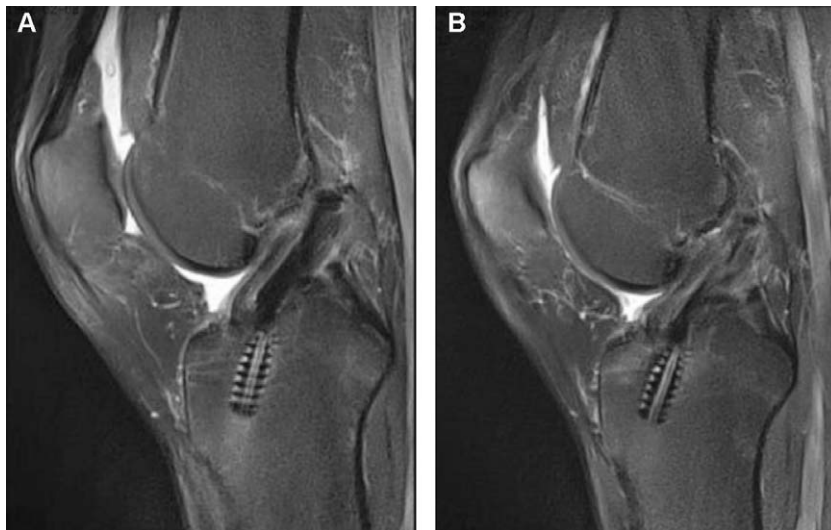
Figure 3 T2 proton density-weighted sagittal images with fat-sat. A. MRI aspect of the graft at 3 months post-surgery. The graft appears in low signal intensity and is easily distinguishable from the ACL stump, which appears in higher signal intensity. B. At 6 months, the graft signal intensity has increased and becomes similar to the ACL stump.

synovial coverage in a second look arthroscopy study [30]. The presence of proprioceptive neuroreceptors in the ACL remnants and their importance for a possible re-innervation of ACL grafts have been pointed out by Lee et al. and Georgoulis et al. [16,31]. Ochi et al. [14,15], in their series of augmentation procedures for partial ACL ruptures, found a better joint position sense in patients conserving a part of the native ACL.

Besides the biological and histological aspects, the mechanical properties of ACL scar tissue in the intercondylar notch have been demonstrated by many authors [8—10]. The presence of a tibial remnant [33] and, moreover, its scarring to the roof or the lateral wall of the intercondylar notch reduces anterior laxity significantly [10,34].

In order to have a sufficient remnant of the ACL, the delay between the initial trauma and surgery remains an issue. Panisset et al. examined the scar pattern of 418 ACL tears on MRI scans and by arthroscopy. They noticed an increasing retraction of the tibial remnant depending on the delay between injury and reconstruction procedure [9]. From a histological point of view, Murray et al. [12] supposed the first weeks after injury to be the most appropriate delay for reconstruction because of synovial, vascular and cell proliferation during this phase. However, except in the case of a bucket handle tear of the meniscus or in high-level athletes, ACL reconstruction is usually delayed. Moreover, in our experience regarding ACL reconstructions within 3 weeks after trauma, the ACL stump was still in the inflammatory phase and extremely soft. We observed a ''bulging'' of the synovial sleeve at the tibial insertion of the ACL graft causing impingement and extension deficit. In this case, the stump has to be debrided or fixed to the proximal part of the graft. Thus, we recommend ACL reconstruction after 3 weeks from injury to be able to pass the graft in the tibial remnant. This period is corresponding to the phases 2 and 3 described by Murray et al. [12]. Delay for several months after the injury potentially risks too small a remnant due to its natural

retraction [9,12,32]. In such a case, only limited coverage of the graft will be possible.

Finally, anatomic positioning and graft fixation remain crucial conditions for successful ACL reconstruction. Our landmark for anatomic femoral tunnel placement is the native ACL footprint as recommended by other authors [35]. The outside-in femoral tunnel procedure is a reliable and precise way to achieve an anatomic femoral tunnel placement even in a minimally debrided notch [7].

Lee et al. described a remnant preserving technique for ACL reconstruction passing the graft through the intact tibial remnant [17]. In their study, two convergent guide wires were inserted in an outside-in manner through a 3- to 4-cm lateral skin incision and the over the top landmark was used as a reference. A closed end femoral socket was performed from the anteromedial portal with an adapted curved curette along the 2 guide wires. The quadrupled hamstring graft was left attached to the tibia and femoral fixation was done by sutures on a cortical bridge. The outside-in technique refers to the ACL femoral footprint as landmark to position the femoral tunnel [35]. Using a tripled semitendinosus graft allows the surgeon to obtain an appropriate graft size leaving the gracilis tendon in place. Preserving its tibial insertion gives additional security to the interference screw fixation and also improves the graft revascularisation [36]. In opposition to a socket prepared with an inside-out technique, the entirely drilled femoral tunnel enables tensioning the graft easily after tibial fixation. Femoral graft fixation by interference screw can be carried out safely without the risk of damaging the graft.

We are aware that this article is only a technical note and advantages of our technique have to be proven in further studies, especially the effect on subsequent graft rupture rate. Another weakness is that up to now, we do not have a reliable method to measure graft revascularisation and healing in the first year after surgery. MRI findings in this period cannot be definitely interpreted [37] and further studies are required to investigate any possible correlation between MRI

findings and graft viability. Finally, our method is technically demanding because of the minimal notch debridement. However, this outside-in technique allows reliable anatomic positioning of the tunnels with minimal debridement and easy graft fixation with interference screw.

Conflict of interest

None.

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