Technical Note

Advanced Anterior Cruciate Ligament Repair and Reconstruction Techniques for Different Rupture Types

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Abstract: Literature concerning anterior cruciate ligament (ACL) reconstruction has increased in both scope and sophistication during the last decades. Heretofore, the principle focus has been on graft choice comparisons, the appropriate handling of co-injuries such as meniscal tears, cartilage lesions, as well as extra-articular ligament injuries. Despite the accumulated knowledge, there is still a lack of clarity concerning a therapy algorithm for different rupture types. With different consequences in therapy strategy, rupture types were differentiated as (1) subsynovial ACL tears/stretch injury and proximal avulsion tears, (2) single-bundle tear (anteromedial/posterolateral), and (3) total ACL rupture. The article presented here provides an overview of recommended operative therapy strategies for different rupture types of the ACL. Within the past decade, advances in arthroscopic technology coupled with rigorous scientific inquiry have resulted in significantly improved treatment options. With these developments in mind, ACL surgery and postoperative therapy can and should be performed in a manner befitting the patient's individual circumstances. Furthermore, intra- and postoperative suggestions including vancomycin graft-coating, as well as an accelerated "Early Active Rehabilitation" program, including early active physiotherapy without postoperative bracing, as well as additional postoperative extracorporeal shock-wave therapy are recommended.

Injury of the anterior cruciate ligament (ACL) is common among physically active patients. Meniscal tears and osteoarthritis are frequent outcomes of the resulting recurrent knee instability.[1] Therefore, surgical reconstruction—especially in patients who wish to return to sporting activity—is recommended.[2] To date, various surgical techniques with different graft choices are available. The hamstring tendon graft is the most frequently used method in ACL reconstruction.[3] Growing scientific and clinical interests focus on more biological reconstruction as preservation of the tibial hamstring tendon insertion or additional extra-articular control of the rotatory instability as the anterolateral ligament (ALL) reconstruction.[4,5]

Recently, different techniques focusing on direct ACL repair have been described.[6-8] Of particular note, the "Healing Response Technique" has demonstrated effectiveness by recruiting bone marrow stem cells through making holes at the femoral attachment in acute complete proximal tears.[9] Also, different reinsertion techniques with anchor systems or "internal bracing" for femoral avulsion tears have been published in recent years.[7,8,10]

Ultimately, due to the high complication rate reflected in the literature despite ongoing research coupled with the long return-to-sports duration as well as the high vulnerability of the repaired/reconstructed ACL in this period, there is still an obvious need for improvement.[11] The article presented here provides an overview of different rupture types and recommended operative therapy strategies. Furthermore, a discussion of additional treatment possibilities as well as suggestions are presented.

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The authors report the following potential conflicts of interest or sources of funding: P.W. is an instructor and consultant for Arthrex. He did not receive any funding. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received January 8, 2020; accepted March 15, 2020.

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2212-6287/2041

https://doi.org/10.1016/j.eats.2020.03.015

Surgical Techniques for Different Rupture Types

All techniques require the patient to be placed in a supine position. We use a leg holder and a high thigh tourniquet. The tourniquet is positioned per protocol, although not routinely inflated. Knee flexion of up to 120° must be allowed in case of anteromedial (AM) drilling if necessary. Antibiotic prophylaxis is administered via a single-shot application as standard. A high anterolateral arthroscopic portal and a suprameniscal AM portal, under visualization via the arthroscope, are recommended as standard portals. After a standard diagnostic arthroscopy of knee with a 30° optic device and, if necessary meniscal repair, the ACL is carefully examined with an arthroscopic examination hook. For better visualization of the medial wall of the lateral femoral condyle and the femoral ACL attachment, a central portal is recommended.

Subsynovial ACL Tear/Stretch Injury and Proximal Avulsion Tear

In case of an intact synovial sheet and a tear of one or both ACL bundles, additional examinations regarding the subsynovial rupture localization must be undertaken. In proximal avulsion injuries (Fig 1) with or without an intact synovial sheet, a single-bundle reinsertion, or—in the event of both ACL bundles—a double-bundle reinsertion is recommended as published previously.[7] Per this reinsertion, the bundles are grasped and a nonabsorbable no. 2 FiberWire (Arthrex, Naples, FL) or a comparable thread is passed through each bundle (Fig 2). In addition, a healing response technique with 2 to 3 microfractures for each footprint is performed with a 45° microfracture awl to stimulate bone–marrow stem cell extravasation.[9] The bundles

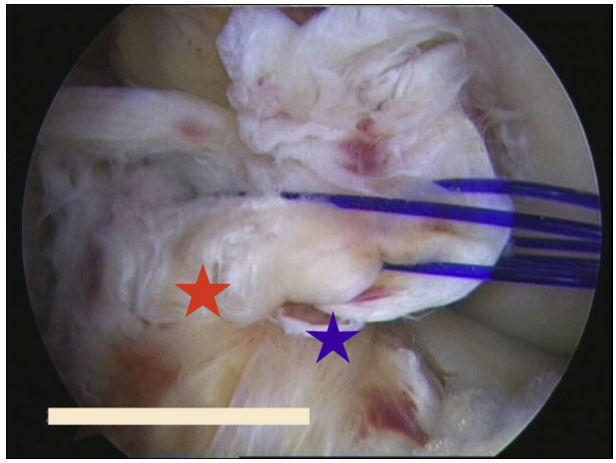

Fig 2. Right knee with patient in supine position. Double-bundle reinsertion of an anterior cruciate ligament proximal avulsion tear. Posterolateral bundle (red star) and anteromedial bundle (violet star) are grasped with a thread from the anteromedial portal.

are then reinserted by PushLock anchors (Arthrex) at 120° (PL bundle) respective to 90° (AM bundle) knee flexion (Fig 3).[7] To avoid soft-tissue interposition during suture passage, partial Hoffa fat pad resection is recommended. Extensive tightening of the sutures must be avoided to ensure adequate blood supply to the bundles.

Alternatively, in cases of proximal avulsion injuries with or without an intact synovial sheet, but also in midsubstance tears with intact synovial sheet (Fig 4), repair of one or both ACL bundles in combination with internal bracing is recommended.[8] Different techniques have been described. Delaloye et al.[10] showed a technique in combination with ALL reconstruction. For ACL repair with internal bracing, we recommend drilling a tibial tunnel in an ACL-sparing manner.[12] A

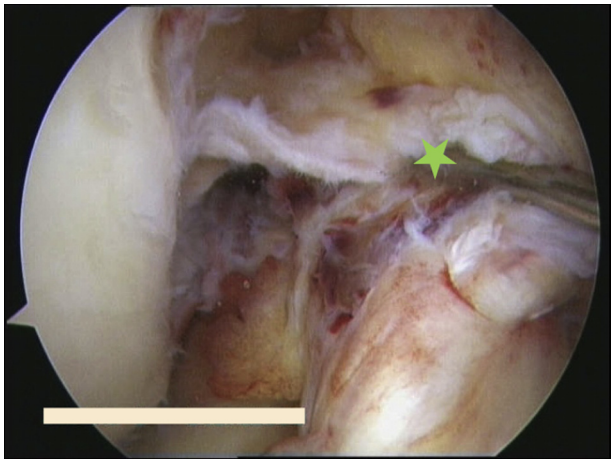

Fig 1. Right knee with patient in supine position. Arthroscopic view via a central portal: proximal avulsion tear of the anterior cruciate ligament (green star) examining with a hook.

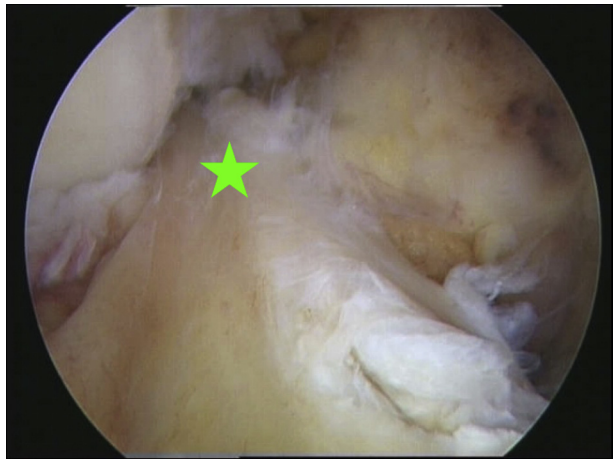

Fig 3. Right knee with patient in supine position. Arthroscopic view via the central portal after anterior cruciate ligament (green star) repair with PushLock anchors.

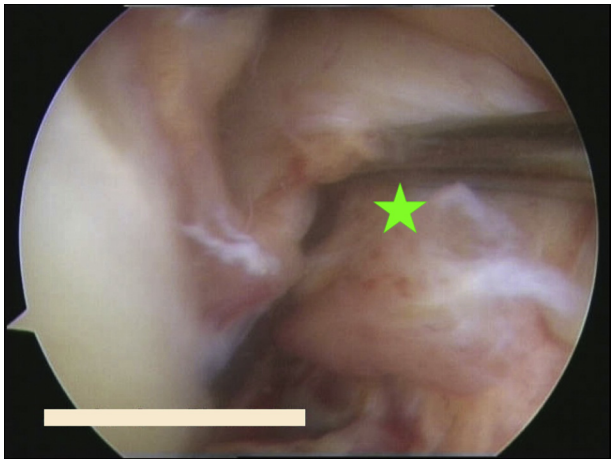

Fig 4. Right knee with patient in supine position. Subsynovial tear/stretch injury of the anterior cruciate ligament (green star) examining with a hook from the anteromedial portal.

FiberStick (Arthrex) is then passed through the tunnel. Afterwards, using the KneeScorpion suture passer (Arthrex), 2 no. 0 FiberLink (Arthrex) cinch sutures are passed through the remnant.[10] With an outside-in femoral guide (Arthrex), a femoral tunnel is drilled positioned at the footprint of the ACL. Independent FiberStick (Arthrex) and TigerStick (Arthrex) are then passed through the femoral tunnel. After linking the TigerStick to the tibial FiberStick, the latter is retrieved, resulting in a TigerStick passing from the tibia to the femur.[10] The FiberTape (Arthrex) is then loaded on a TightRope (Arthrex) button and shuttled through the tunnels. The ACL cinch sutures are then passed through the femoral tunnel and fixed over the TightRope button at 90° knee flexion. In full extension, the internal bracing is then secured with a SwiveLock (Arthrex) anchor (Fig 5).[10]

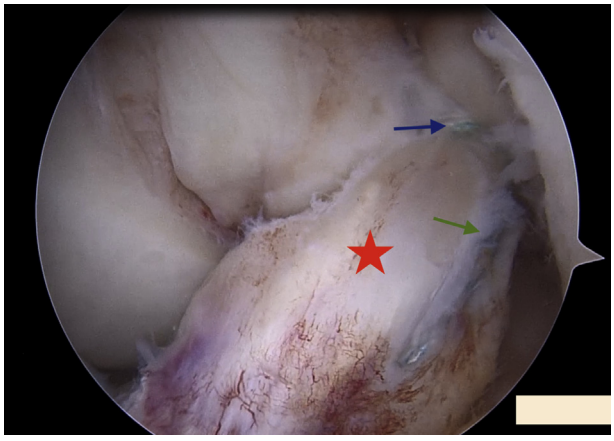

Fig 5. Left knee with patient in supine position. Diagnostic arthroscopic view via an anterolateral portal 5 months after anterior cruciate ligament repair (red star) of a subsynovial tear by internal brace (blue and green arrows: FiberTape and reinsertion thread). (©Arthrex GmbH)

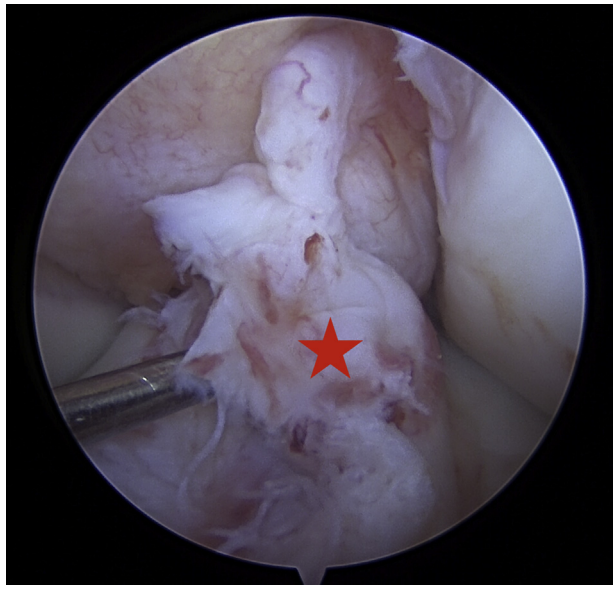

Fig 6. Left knee with patient in supine position. Anterior cruciate ligament single-bundle tear. Anteromedial bundle (red star) examining with a hook from the anteromedial portal.

Single-Bundle Tear (AM/Posterolateral [PL])

In the event a of partial ACL tear (isolated AM bundle/isolated posterolateral bundle), selective bundle reconstruction has recently gained prominence.[13,14] During diagnostic arthroscopy, the ACL is examined. If the intact AM or PL bundle shows structural or functional deficits, conversion to total ACL reconstruction should be performed. As soon as a single-bundle tear is confirmed (Fig 6), graft harvest of one hamstring tendon (semitendinosus tendon or gracilis tendon) is performed, as previously described.[15] Alternatively, a tibial insertion preservation technique

Fig 7. FastThread BioComposite Interference Screw (Arthrex, Naples, FL) is used for tibial fixation in ACL reconstruction. (©Arthrex GmbH)

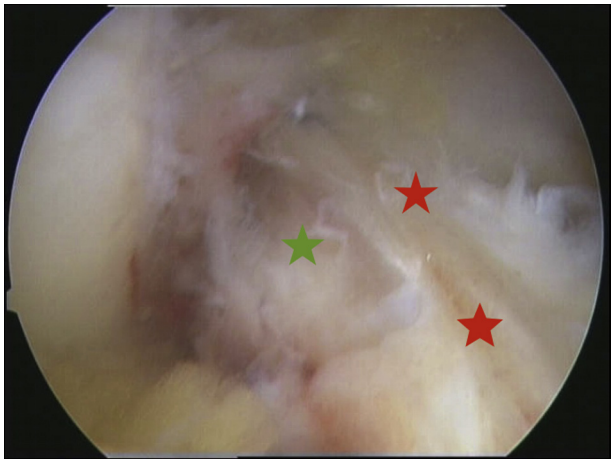

Fig 8. Right knee with patient in supine position. Arthroscopic view via a central portal: posterolateral bundle reconstruction (green star) using Semitendinosus tendon autograft with intact anteromedial bundle (red stars).

could be conducted.[14] For 6.5mm to 7.5mm graft preparation (considering notch size and to avoid overstuffing), a baseball stitch with FiberWire no. 2 is used. Subsequently, the graft is placed in vancomycin solution (5 mg/mL) for presoaking. After arthroscopic preparation of the femoral footprint of the torn ACL bundle according to its anatomy (AM: proximal and anterior in the femoral ACL origin; PL: distal and posterior the femoral ACL origin),[16] a 4-mm drill pin is drilled via the AM portal through the respective bundle origin and the skin laterally at 120° knee flexion. Then, the femoral tunnel is drilled with a cannulated drill bit respectively to graft size. The tibial tunnel is then prepared in accordance to a standard procedure. In case of PL bundle reconstruction, the guide is positioned near the lateral spine and posterior to the AM bundle. In AM reconstruction, the footprint is chosen in the anterior part of the total ACL footprint. Then, a TightRope is loaded with the prepared graft and passed through the bone tunnels by a thread. After pre-tensioning by cycling the knee between 0° and 120° repeatedly, FastThread BioComposite Interference Screw (Arthrex; Fig 7) suitable to the drilled bone

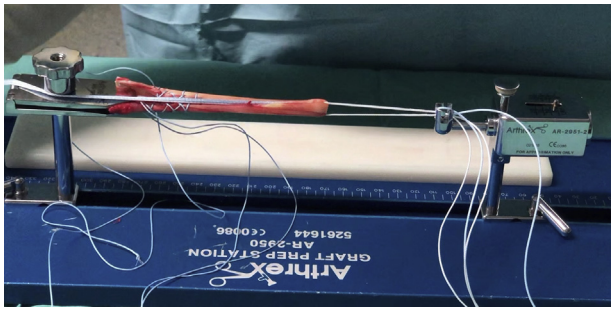

Fig 9. Pre-tensioning of prepared hamstring tendon autograft with incorporated FiberTape.

Fig 10. Presoaking of autograft with a vancomycin solution.

tunnel is used to fix the graft (PL-bundle: 15° knee flexion; AM-bundle: 45° knee flexion) (Fig 8).[17]

Total ACL Rupture (With Video Illustration)

A total ACL reconstruction (Video 1) is performed under the following circumstances: the ACL is chronically ruptured, in the event of a midsubstance rupture, and tibial avulsion. In primary ACL reconstruction, we perform hamstring tendon autograft as a standard procedure.[3] Graft harvesting of semitendinosus and gracilis tendon is conducted by default.[15] Graft preparation is then performed as described previously. The graft is trimmed to 8 to 9 mm in diameter using the baseball stitch with no. 2 FiberWire. Subsequently, the TightRope is loaded with the prepared graft and a FiberTape (Arthrex), and pre-tensioning is carried out (Fig 9). Alternatively, the FiberTape is passed through the button of the TightRope device.[18,19] In addition, a vancomycin solution (5 mg/mL) for presoaking is applied (Fig 10). Simultaneously, after visualization and identification of the bony landmarks, particularly the bifurcation ridge and the lateral intercondylar ridge, the femoral and the tibial footprints are prepared and marked corresponding to their native positions[20] (Figs 11 and 12). The femoral

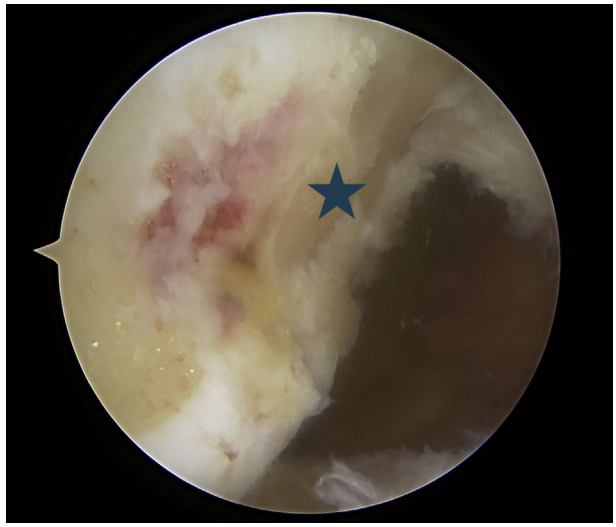

Fig 11. Right knee with patient in supine position. Arthroscopic view via a central portal: Identification and preparation of femoral footprint (blue star) according to the native position.

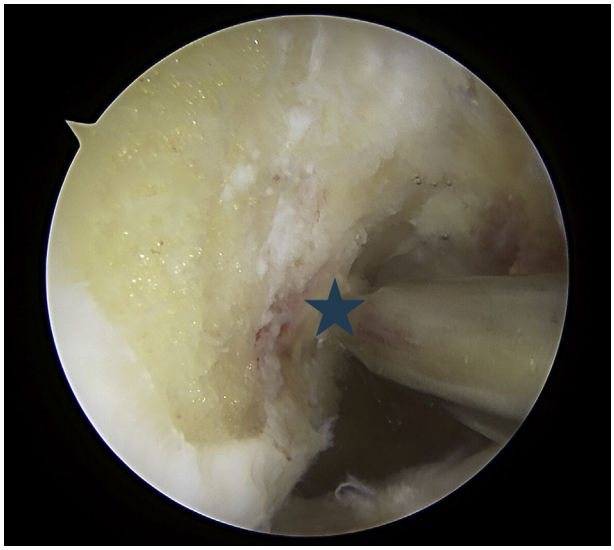

Fig 12. Right knee with patient in supine position. Marking the footprint with a microfracture awl from the anteromedial portal (blue star).

tunnel is then addressed first, with drilling through the AM portal in 120° knee flexion. The tunnel is placed between the AM and PL bundle insertion point (at the lateral bifurcate ridge and below the lateral intercondylar ridge) with a 4-mm drill pin and a cannulated drill bit corresponding to graft size (Fig 13). A thread is then passed percutaneously through the joint, the tunnel, and the lateral cortex and fixed with a clamp. Afterwards, the tibial tunnel is prepared. Consequently, the tibial aiming device (Arthrex) is positioned according to the anatomic tibial footprint as arthroscopically visualized (Fig 14).

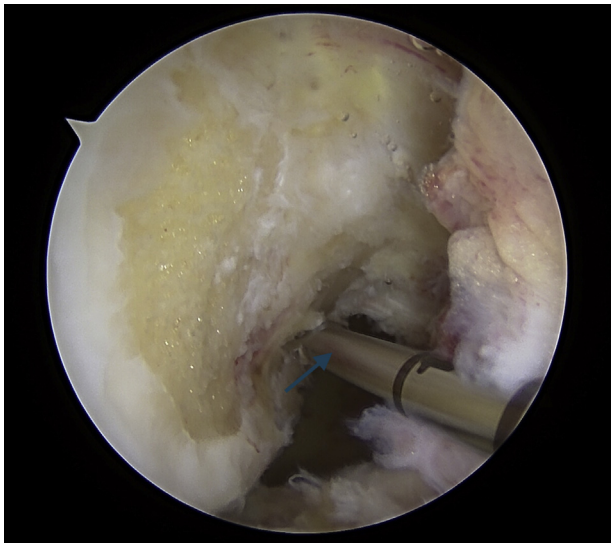

Fig 13. Right knee with patient in supine position. Drilling of the femoral tunnel with a 4-mm drill pin (blue arrow) and a cannulated drill bit respectively to graft size via the anteromedial portal.

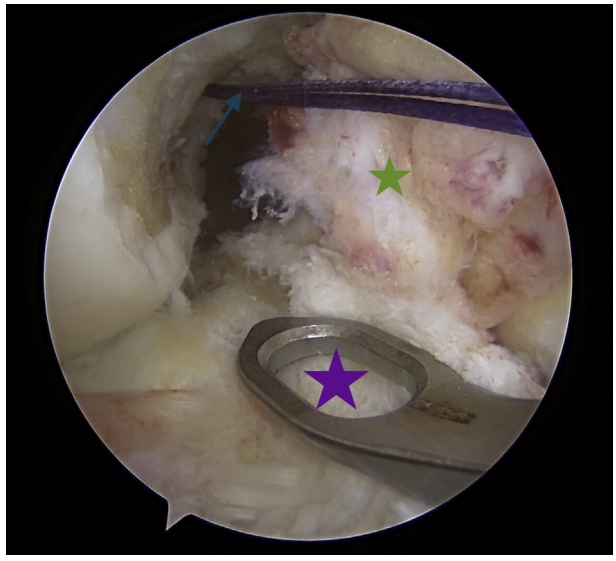

Fig 14. Right knee with patient in supine position. Positioning of the anterior cruciate ligament marking hook at the anatomic tibial footprint via the anteromedial portal (violet star). Green star: intact posterior cruciate ligament. Blue arrow: thread passed through the femoral tunnel.

The aimers position is medial to the tibial tubercle and the tibial tunnel is drilled in accordance with graft size. After potentially pinching soft tissue is shaved smooth, the prepared graft and FiberTape is passed through the tunnels and the TightRope is flipped corresponding to standard femoral fixation (Figs 15 and 16). After cycling the knee between 0° and 120° for preconditioning, a FastThread BioComposite Interference Screw (Arthrex; Fig 7) is used for tibial fixation in a 30° knee flexion (Fig

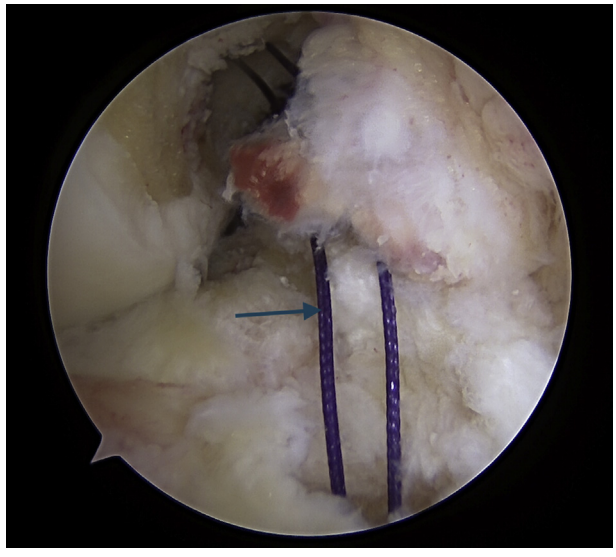

Fig 15. Right knee with patient in supine position. Arthroscopic view via the central portal: A thread passed through the femoral and tibial tunnel (blue arrow).

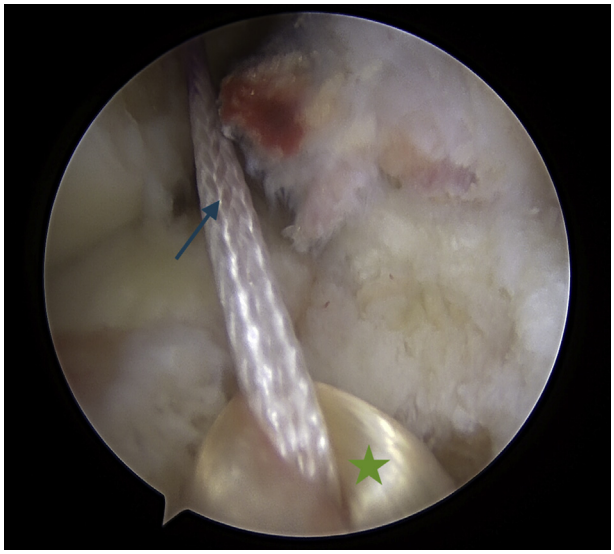

Fig 16. Right knee with patient in supine position. Arthroscopic view via the central portal: Passing of the prepared graft (green star) with FiberTape through the tunnels (blue arrow: anterior cruciate ligament TightRope).

17). Alternatively, the ACL graft is fixed with a SwiveLock (Arthrex) anchor of the same size as the graft diameter is used as an interference screw while the FiberTape is passed through the cannula of the SwiveLock to be fixed subsequently in full extension and neutral rotation with a 4.75-mm SwiveLock anchor.[18] A technique, described previously by Sonnery-Cottet et al.,[12] with preservation of the tibial insertion of the hamstring tendons is performed as an alternative.

After visualization and control of the repaired or reconstructed ACL, skin closure is performed. An intra-articular suction-drainage is not recommended as a matter of routine.

Postoperative Treatment

As per routine, an ultrasound-guided saphenous nerve block is performed for perioperative pain management.[21] In instances of both ACL reconstruction as well as ACL repair, we endorse the "Early Active Rehabilitation" therapy strategy. While undergoing this program, patients focus on immediate full weight-bearing without postoperative bracing. The rehabilitation program also includes isometric muscle activation from the first postoperative day onward. In respect to compression, thermotherapy, and cryotherapy, the Full Leg Boot (GameReady, CoolSystems, Inc., Concord, CA) is used starting on the first postoperative day. Additionally, extracorporeal shock-wave therapy (Storz Medical, Tägerwilen, Switzerland) is applied at weeks 2, 3, and 4 after the operation.[22]

Discussion

The overview contained within these pages is intended to provide surgeons with a broader selection of options through the lens of differentiated factors. The last decade has proven fruitful for both technological and scientific innovation with respect to ACL treatments. It is the authors' opinion that with treatment strategies tailored to patient-specific arthroscopic

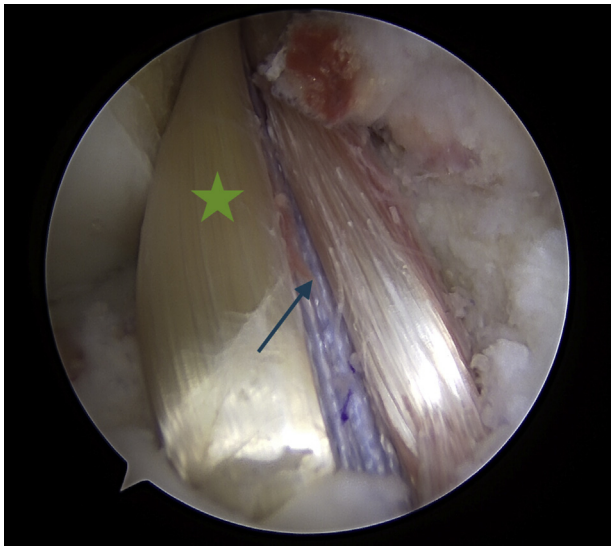

Fig 17. Right knee with patient in supine position. Reconstructed anterior cruciate ligament with hamstring tendon autograft (green star) and incorporated FiberTape (blue arrow).

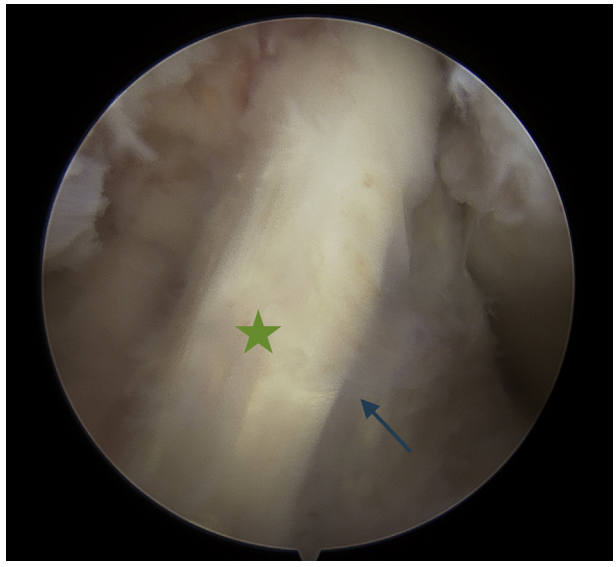

Fig 18. Left knee with patient in supine position. Diagnostic Arthroscopy one year after ACL reconstruction shows intact ACL graft (green star) with incorporated FiberTape (blue arrow) and an intact synovial sheath. (ACL, anterior cruciate ligament.)

Table 1. Pearls and Pitfalls

Pearls	Pitfalls and Risks
For better visualization of the medial wall of the lateral femoral condyle, a central portal is recommended.	Insufficient visualization of the ACL attachment may lead to misinterpretation of rupture type.
Knee flexion of up to 120° must be allowed.	Vancomycin presoaking may lead to autograft enlargement → further size control before implantation.
To avoid posterior wall blow-out during drilling and to ensure correct tunnel placement, we recommend marking and punching the tunnel entrance with a microfracture awl.	To avoid the risk that the graft gets stuck, tibial tunnel entrance exposure and removal of soft tissue and periosteum with the raspatorium are recommended.
Soft tissue should be shaved smooth to avoid potentially pinching.	

ACL, anterior cruciate ligament.

findings, an individualized patient treatment regimen can be effectively used.

An important discussion point hinges on the additional external material used in internal bracing or in augmented ACL reconstruction. Recent research showed in histologic analysis that there is no negative effect on bone tunnel healing or a prolonged inflammation period by the use of FiberTape.[23] Furthermore, the biocompatibility of the FiberTape was confirmed as having no synovial reactions, no cartilage damage, or other functional consequences.[24] We subsequently confirmed these findings macroscopically when we performed re-arthroscopies (see Fig 18). There are many studies showing the beneficial biomechanical effect of FiberTape use in ACL repair as well as reconstruction.[19,23]

In our autograft technique, we use vancomycin for presoaking of the tendons as a matter of standard procedure. The use of vancomycin reduces the risk of infection of the knee joint significantly. In a group of 1135 patients, intravenous and local application of antibiotics was compared. The local vancomycin group (870 patients) suffered no knee infection.[25] Furthermore, other studies showed, that there is no additional risk of arthrofibrosis or graft failure by the use of vancomycin for presoaking.[26]

Avoiding hamstring detachment at the pes anserinus plays an increasingly important role in ACL surgery. Earlier studies described techniques as well as performed histologic analysis concerning graft maturation and so-called "ligamentization."[5,7,12,27] In addition to preserving viability, this process appears to bypass avascular necrosis and revascularization when compared to free hamstring autografts.[28] Recent histologic preclinical investigations showed improved bone—tendon healing and biomechanical benefits in this way.[5]

Reconstruction of the ALL has gained importance in revision ACL surgery, but also in primary ALL reconstruction as well as in ACL repair. As an option for controlling rotatory instability, reconstruction of the ALL has shown biomechanical benefits on tibial internal rotation with increasing knee flexion and during pivot shift.[4] The indications for reconstruction is given in ACL revision, young patients, combined meniscal repair, as well as high grade of pivot shift.[4]

Neuromechanical decoupling after ACL reconstruction surgeries and evidence of altered control of the knee as well as sensorimotor perception were published recently.[29] To counteract this, early rehabilitation strategies were shown to help improve postoperative outcome due to alterations in neuromuscular quadriceps activation.[30] This underlines the importance of physiotherapy—including active exercising—from the earliest possible time point after reconstruction surgery. The effect of additional extracorporeal shockwave therapy in the postoperative rehabilitation stage has also been documented previously.[22] Improved results in

Table 2. Advantages and Disadvantages

Advantages	Disadvantages
Individualized surgical techniques for different rupture- and patient types enable optimal outcome for different requirements.	Greater surgical challenge to master various surgical techniques.
ACL repair techniques and hamstring insertion preservation combine biological self-healing and surgical stabilization.	5-10 minutes surgery time prolongation using hamstring insertion preservation technique.
Biomechanical improvement with additional FiberTape use.	Additional foreign material implantation (but without any tissue reaction).
Significant reduction of infection risk by vancomycin use.	

ACL, anterior cruciate ligament.

postoperative knee scores as well as a reduction of tibia tunnel enlargement have been shown.[22] Accordingly, an investigation concerning effect of extracorporeal shockwave therapy on graft maturation has already been initiated by our study group.

This article should provide suggestions for ACL treatment with respect to different rupture types. Thanks to advances brought about by intensive scientific focus and developments in arthroscopic technology, treatment strategies have similarly developed in scope and specificity. Accordingly, ACL surgery needs to be performed in a more individual way with respect to different treatment options.

Acknowledgments

The authors thank T. A. Vacca and B. Sonnery-Cottet, M.D., for their helpful contributions.

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