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ORIGINAL STUDY

Surgical treatment of the Anterior Cruciate Ligament Rupture : where do we stand today?

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The rupture of the anterior cruciate ligament is one of the most common orthopaedic injuries. This review gives an overview of the surgical treatment of the ACL rupture. A correct knowledge of the anatomy of the ACL is crucial in treating this injury. Recent studies describe the ACl as flat rather than divided in distinct structural bundles. Reconstructive and primary repair techniques can be used to approach this native anatomy. Reconstructive surgery of the ACL still is the golden standard in ACL surgery. An individualized approach is key and should be used. However, ACL reconstruction is not always a success. Return to preinjury of sports only reaches 65% and ACL-reconstructed knees are prone to osteoarthritis. Previous attempts at the primary repair of the ACL were archaic and had disappointing results. Modern diagnostics, operative and biological techniques and strict patient selection could initiate a revival of this technique.

Keywords: Anterior cruciate ligament rupture; ACL; ACL reconstruction; ACL primary repair; ACL anatomy

INTRODUCTION

The rupture of the anterior cruciate ligament (ACL) is one of the most common orthopaedic injuries worldwide. In the United States of America, estimates alone suggest an annual incidence of 35 ACL ruptures per 100,000 people of all ages (*21*). Keeping in mind that the ACL is one of the key stabilizers of the knee joint, it is not hard to imagine that an injury of the ACL can have devastating effects. Injuries often result in joint effusion, altered movement, muscle weakness, reduced functional performance and may lead to a temporary or definitive loss of sports participation among young athletes (*14*). An untreated ACL rupture will cause the patient pain and a sustained sense of instability. Long-term clinical sequelae of a persisting ACL rupture include meniscal tears, chondral lesions and an increased risk of early onset osteoarthritis (*18,33,21*). To prevent the latter, a surgical solution is needed in most cases. The decision between an operative and non-operative treatment of the ACL rupture is multifactorial and must be individualized for each patient. Age, current and future activity level and presence of concomitant injuries are elements to consider in making a decision (*21*). However, if the patient is a young and active person, a surgical approach is necessary to restore his or her functional capacities. Keeping in mind that most ACL injuries are sports related (*14,18*), one could argue that a surgical approach may be needed in most cases of ACL rupture.

As of today, reconstructing the ACL with an autologous graft is still the golden standard.

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However, this technique also has its downsides. It has variable outcomes and is associated with a high risk of post-traumatic osteoarthritis within 20 years of injury. Furthermore, athletes who undergo a reconstruction are not always capable of returning to their pre-injury activity level and are at high risk of a second knee injury (*14,18,35,25,21,36*). Where the primary repair of the ACL was once condemned to the history books, late research in animal models and clinical application in case-series have made primary repair a possible alternative in some cases of ACL rupture.

This review will start with summarizing the current anatomical knowledge of the ACL. Each surgical approach to restore the ACL tries to recreate its original anatomical dimensions and by doing so its function. Next, a brief overview will be given of today's golden standard in ACL surgery, i.e. ACL reconstruction. Finally, the primary repair of the ACL will be reviewed.

ANATOMY

The anatomy and function of the anterior cruciate ligament have been researched for many years. The first description of the ACL dates back to 3000 BC when it was documented on a papyrus scroll. It received its original name "ligamentu genu cruciate" by Claudius Galenus of Pergamon (129-199 BC) (*37*). As time and science progressed, the orthopaedic community made big steps in understanding and treating injuries of the ACL. In 1921 AD, it was Bircher who was the first to succeed in performing an arthroscopy on a knee joint. Only several decades later, in 1981, an arthroscopic reconstruction of the ACL was performed and documented by Dandy (*37*). The key in treating an injury of the anterior cruciate ligament is restoring its original anatomy. For this to happen, a profound understanding of the anatomy and thereby its function is necessary.

The ACL is a band of dense connective tissue that runs between the femur and the tibia. It originates from the medial wall of the lateral condyle and runs obliquely through the intercondylar fossa to its insertion on the medial tibial eminence. The ligament is covered with a synovial membrane, which makes it an intra-articular but extra-synovial structure (*37*).

The bundle concept has long been the standard in approaching the ACL. Many authors describe the ACL as consisting out of two bundles, i.e. the anteromedial bundle and the posterolateral bundle. Both bundles are named after their tibial insertion. Lately, the bundle concept has been under siege by studies that show that the ACL midsubstance is actually more ribbon-like (*28-30,19*). A cadaveric study by Robert Smigielsky and his colleagues on 111 cadaver knees concluded that the ACL has a flat ribbon-like aspect from its femoral insertion to its midsubstance in all dissected knees (*30*). A clear separation into bundles was deemed impossible. Concerning the femoral origin of the ACL, the authors stated that the origin could be divided in a direct insertion and an indirect insertion. The direct insertion consists of dense collagen fibers, which connect to the bone by a fibrocartilagenous layer, just posterior and along the lateral intercondylar ridge or "resident's ridge". The indirect insertion is located just posterior of the direct insertion and consists of fan-like extension fibers of the direct insertion that spread out like a fan on the posterior condyle (*30*). The flat ribbon-like aspect of the midsubstance of the ACL was also described by Siebold and his colleagues in a cadaveric study of 20 cadaver knees (*29*). They also described the tibial insertion of the ACL as consisting out of a direct and an indirect insertion. According to them, the direct insertion is a long but narrow "C"-shaped insertion of the midsubstance fibers. In the centre of this "C", there are no ACL fibers. It consists of the bony insertion of the anterior root of the lateral meniscus and is covered with fat. The indirect insertion would then be the anteriorly and broader "fan"-like extension of the midsubstance fibers that spreads out towards the anterior rim of the tibial plateau. Together, the direct and indirect insertion form a figure resembling a duck's foot, which represents the bony insertion of the ACL (*29*).

The existence of a clear distinction between an anteromedial and posterolateral bundle has always been a subject of controversy. However, this double bundle concept was at the base of the double bundle reconstruction technique that is now performed all over the world. Both the previously mentioned studies (*29,30*) describe the midsubstance as "flat" and "ribbon"-like. A distinct anteromedial and posterolateral bundle was not found during dissection and after examination. Smigielsky and Siebold both state that bundles may be artificially created by the twisted, flat ribbon-like structure during flexion of the knee joint due to different tibial and femoral alignment (*30,29*). This confirms previous findings stating that the ACL is rather flat than oval and that it consists out of a continuum of fascicles (*13,1,20*). Siebold and his colleagues did not even find a clear posterolateral tibial attachment of the ACL. The posterior fibers of the direct insertion were aligned along the medial tibial spine and were therefore named posteromedial fibres (*29*). These findings can further optimize surgical results in ACL repair and reconstruction, because the flat shape of the ACL and the specific anatomical footprint of its insertion and origin should be restored during repair or reconstruction.

RECONSTRUCTION

Reconstruction of the anterior cruciate ligament is still today's golden standard in ACL surgery. The procedure consists of removing the torn ACL remnants and replacing the entire ACL by an auto- or allograft, which is kept in place through bony tunnels in the femur and tibia. Today, surgeons strive to reconstruct an ACL as closely as possible to its original anatomy. Therefore, each ACL surgery should be tailored to each specific patient. This creates a demand for individual anatomical reconstructions. Four principles were described earlier, i.e. reconstructing both functional bundles of the ACL, placing the grafts anatomically, tensioning the graft in accordance with native tensioning patterns and customizing the surgery for each individual patient (*15*). This review will focus on the first two principles and will try to align them with the new anatomical findings described earlier.

Grafts and bundles

Reconstructive surgery of the ACL tries to approximate the described anatomy of the ACL. Based on earlier descriptions of an anteromedial and posterolateral bundle, surgeons tried to use grafts in a way that resembled this configuration. Frequently used grafts are the bone – patellar tendon – bone autograft, the quadriceps tendon autograft, the hamstring tendon autograft and an allograft. Both advantages and disadvantages of these frequently used grafts are described elsewhere (*21*). Once the type of graft is chosen, the surgeon has the choice of either using a single-bundle technique or a double-bundle technique. The single-bundle reconstruction is still the most used reconstruction technique. The double bundle technique is more popular in Europe and Asia than in the United States of America (*21,33*). The single bundle technique mainly focuses on restoring the function of the anteromedial bundle, i.e. restoring the anterior stability, but it lacks in restoring rotational stability. The double bundle technique reconstructs both the anteromedial and the posterolateral bundle and should therefore also restore rotational stability and in general mimic the original function of the ACL more accurately (*26,33*). A Cochrane review concerning this topic was performed in 2012 consisting out of 17 randomized or quasi-randomized controlled trials (*33*). Its conclusions were that there are no statistically or clinically significant differences between double-bundle and single-bundle reconstructions in the subjective functional knee scores in the intermediate or long term. There were also no significant differences between the two groups in adverse effects or complications. However, at long term follow-up, statistically significant differences emerged in favor of the double-bundle group in terms of IKDC knee examination, stability measurements with the KT-1000 arhtrometer and rotational stability tests with the pivot shift test. Additionally, double-bundle reconstructions were seen to have lesser meniscal injuries and less cases of traumatic ACL rupture. Nonetheless, in an individualized reconstruction, one should try to shape the graft to the needs of the patient and a single-bundle could be favorable (*15,10*). A comprehensive flowchart that helps the surgeon in making this particular decision has been described (*10*).

At first sight, the bundle concept in ACL reconstruction doesn't seem compatible with the flat and ribbon-like anatomy of the ACL. However, the patellar tendon and the quadriceps tendon have a natural flat shape and can be used in a single bundle technique to mimic the original flat shape of the ACL. When using the hamstring tendons, they have to be aligned in a double bundle technique to reconstruct the flat shape of the ACL (*30,29*). By doing this, the bundle concept can be used to reconstruct the ACL in its native anatomy.

Tunnel placement

Proper placement of the tunnels is key in performing an excellent reconstruction procedure. The aim is to restore the native insertion site of the ACL. Not achieving proper tunnel placement can lead to graft impingement, graft failure, a flexion deficit or remaining instability of the knee joint (*37,21*). All of these complications can lead to further damage of the joint and speeding up the process of osteoarthritis. There has been a lot of literature about the exact shape and position of the femoral and tibial insertions of the ACL. However, recent publications about a flat ACL anatomy may change the way the insertion of the ACL is being reconstructed today (*29,30,24,19*).

In these publications, the femoral insertion was described as consisting out of a direct and an indirect insertion (*19,24,30*). The direct insertion is the attachment of the midsubstance fibers and has the same flat-like appearance as the midsubstance part of the ACL. It also functions as the main anchorage point of the soft tissue to the femoral bone. The fan-like indirect insertion has an influence on this anchorage process as well. It allows certain shear movements, but plays a smaller role than the direct insertion and is far more difficult to reconstruct.

The tibial insertion consists out of a direct and an indirect insertion as well (*29*). Like its femoral counterpart, the direct tibial insertion consists out of the inserting midsubstance fibers and has a flat appearance. It is more difficult to reconstruct than its femoral counterpart because it is C-shaped and its central part does not consist of ACL fibers, but out of the bony attachment of the lateral meniscus. Siebold also concluded that there are no posterolateral fibers, only anteromedial and posteromedial fibers (*29*). The tibial indirect insertion consists out of fan-like extension fibers of the midsubstance, but these, like their femoral counterparts, are difficult to reconstruct.

For the actual placement of the bony tunnels, the configuration as described below is suggested (*29,30*). The femoral tunnel should be at the direct insertion of the native ACL. It has a flat appearance, just like the midsubstance, and by using a flat graft, It is possible to mimic the native midsubstance fibers and mimic the fibers of the direct femoral insertion (*30*). The tibial tunnel is more difficult to reconstruct because of the C-shaped insertion and the central part not consisting out of ACL fibres. Because of this, an anteromedial bone tunnel could be a valid option when employing a single bundle reconstruction. For a double bundle reconstruction, both an anteromedial and a posteromedial bone tunnel could be used. Both a central or posterolateral bone tunnel are non-anatomical, they may compromise biomechanics and damage the insertion of the anterior root of the lateral meniscus (29).

ACL reconstruction outcomes

Most ACL ruptures are sports related (*14,18,3*). If an athlete wants to resume his athletic activities at his preinjury level, a reconstruction is necessary in most cases (*21*). The success of the intervention can be measured in the "return to sports" percentage. An excellent systematic review and meta-analysis was performed by Ardern et al. in 2014 (*3*). They combined data from over 7000 participants and produced the following conclusions: 1) 81% of patients returned to some form of sports after surgery, 2) 65% returned to their previous level of sports after surgery, 3) 55% returned to competitive sports, 4) younger age, male sex, a symmetrical knee function and a positive psychological response favored a return to preinjury level sports, 5) elite-athletes had greater odds at returning to sports than non-elite athletes and 6) receiving a hamstring tendon autograft favored returning to competitive level sports, whereas receiving a bone – patellar tendon – bone autograft favored returning to preinjury level sports. The authors stated that a postoperative rehabilitation program, that not only focuses on physical rehabilitation but also on psychological support, is key in returning to sports. ACL reconstruction is also advocated for patients who intend to return to physically demanding occupations. If these patients do not get a reconstruction, repeating episodes of instability will interfere with their activities of daily life (*2*).

A remaining problem after an ACL reconstruction is the rate of posttraumatic osteoarthritis (*18,21,34,35,5*). A meta-analysis of Claes et al. (*5*) combined data from 1554 patients who received an ACL reconstruction between 1978 and 1997. At a minimum of ten years of follow-up, 28% of the knees showed radiological signs of osteoarthritis (IKDC grade C or D). The authors also state that preserving the menisci is key in preventing premature osteoarthritis in an ACL reconstructed knee. 42% of patients who underwent a meniscectomy had radiographical findings of osteoarthritis compared to 19% who had preserved menisci (OR 3,54). Although more than one in four patients who underwent reconstruction had premature osteoarthritis, two things should be noted. First, the meta-analysis reports about the objective measurement of osteoarthritis, no details are given about the subjective complaints of the patients. Second, the prevalence of osteoarthritis post ACL reconstruction that resulted out of this meta-analysis is much lower than previously reported prevalence numbers (*5*).

PRIMARY REPAIR

Why primary repair may be necessary

The primary ligamentous repair of the anterior cruciate ligament was studied in the late decades of the previous century, which led to long-term follow-up studies published several years ago *(32,11,27,17,9,31*). The procedure consisted out of an arthrotomy followed by an open repair with non-absorbable sutures. Initial short term results were good: Feagin et al. reported good to excellent results at two year follow-up in 83% of the patients (*11,32*). Yet, their five year follow-up paper showed disappointing results: a high number of patients reported pain (71%), swelling (66%) and instability (94%). Also, 75% of patients reported impairment during athletic activities and 38% of patients had difficulties in performing daily activities. This paper can be seen as the reason why primary repair was abandoned and research shifted to reconstructive solutions for ACL tears (*11*). Long-term follow-up studies confirmed the problems with this open primary repair. They showed poor results in almost 30% of all patients (*32,31,9*). However, it is noteworthy that these long-term follow-up studies were based on the initial patient groups that were treated in the 70's and 80's. Those ACL ruptures were archaically treated through an arthrotomy with extensive postoperative cast immobilization and little respect for the biology of the ACL. In addition, diagnostic possibilities were less potent than they are today. Another fact to consider is that a subgroup of the patients in these studies actually did have good results. Strand et al. stated that 40 % of their patients had good or excellent Lysholm scores and 41% had less than 3 mm laxity measured by the KT-1000 (*31*). The initial patient cohorts were mixed, including patients of different age groups, different tear types and concomitant knee injuries such as meniscal injuries. It was Sherman et al. (*27*), who stated that Type 1 ACL tears trended to have better results than Type 4 ACL tears.

Despite the fact that ACL reconstruction is today's golden standard treatment for ACL ruptures, it seems that there are arguments that a revamped version of the primary repair may have its place in treatment of an ACL rupture (Fig. 1). As stated above, type 1 tears that were treated with a primary repair trended towards better postoperative clinically objective scores (*27*). Another subgroup that could benefit from this new technique are adolescents and skeletally immature patients, where the incidence of ACL ruptures is rising. In this age group, a higher failure rate of ACL reconstruction surgery is observed than in other age groups. Up to 25% of these patients experience problems postoperatively (*35,4*). Also, there are still mixed opinions about transphyseal grafts and their risk for limb length and angular deformities. A technique

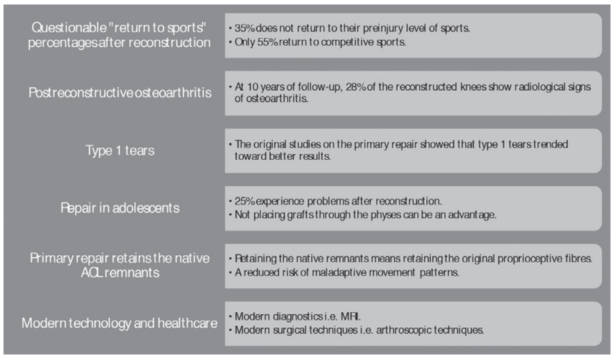

Fig. 1. - A schematic overview of reasons tu pursue the aprimary repair.

that could spare the physes would eliminate this problem. A third argument in pursuing the primary repair is that with retaining the original ACL remnants, the proprioceptive nerve fibers and the complex architecture of the native insertion sites are retained as well (*36,18,12*). A disruption in proprioception and original biomechanics may lead to maladaptive movement patterns which may predispose to osteoarthritis and functional limitations (*7,8*). Finally, as mentioned earlier, although ACL reconstruction yields good short- and midterm results, osteoarthritis is still a long term problem after ACL-reconstruction. So, once the target group is selected carefully (type 1 tear, good tissue quality, young person), a primary repair of the anterior cruciate ligament may be a valid option.

Techniques and results

The primary repair pursues the path of physiological healing. By approximating the remnants of a torn ligament with sutures, five phases of healing should occur, i.e. inflammation, cellular proliferation, vascular proliferation, vascular pruning and collagen healing. A critical component in this process is the formation of a fibrin-platelet clot at the site of the defect (*12,16,18,22,25,35,34*). This clot not only functions as a primary scaffolding to fill up the defect, but it is also an important source of growth factors and cytokines, which are necessary for an adequate regeneration of the ACL tissue. However, unlike extra-articular ligaments, such as the medial collateral ligament, the ACL does not form such a clot and as a result the healing process is delayed (*18,35*). The inability to form a clot is caused by the presence of synovial fluid. Synovial fluid has a continuous flow in the joint which causes the blood to spread and present as haemarthrosis (*18*). Synovial fluid also contains plasmin, which prematurly breaks down the fibrin containing clot (*35*). In addition, ACL fibroblasts are inhibited by synovial fluid (*35*).

The bio-enhanced primary repair addresses this problem. This technique has been used in multiple animal studies and has shown promising results (*16,22,25,34,35,12*). It consists out of two parts. First, a mechanical repair of the ACL is performed. The tibial stump of the ACL is reattached to the femur or the femoral stump with sutures or suture anchors. Most studies use a suture bridge, which is created between the femur and the tibia and functions as a stress shield for the repair by gradually putting stress on the repair as the sutures are absorbed by the body (*34,35,12,22*). In a second step, a collagen-platelet-composite is added to the repair (*34,35,22,16,18*). The collagen scaffolding is sutured in close relation and in alignment with the ACL remnants. It functions as an artificial scaffold that bridges the defect and gives structural support, which would normally be given by the fibrin-platelet clot. This scaffold is soaked with platelet containing solution, mostly platelet-rich plasma (PRP). PRP is the source of the cytokines and growth factors that are necessary for ACL tissue regeneration.

Results of these animal studies look promising. Vavken *et al.* (*34*) proved that there was no clinically significant difference in biomechanical outcome between bio-enhanced repair and ACL reconstruction in a porcine model. However, it should be noted that the follow-up time was only 15 weeks. Murray *et al*. (*22*) confirmed these findings at a prolonged follow-up time of 12 months. Additionally, they stated that there was a strong trend for less macroscopical cartilage damage in the bio-enhanced repair than in the ACL reconstruction. In the future, controlled human trials will be necessary to ensure safety and efficacy before these techniques are used in clinical practice.

Recently, DiFelice et al. published a case series on a different approach of primary repair (*6*). They solely used a mechanical repair using two suture anchors in order to reattach the tibial stump to its femoral footprint. Patient selection was very strict: only type 1, proximal avulsion tears with excellent tissue quality were selected. Their selection criteria are mainly based on two other studies. First, the paper of Sherman et al. (*27*), who stated that type 1 tears trended to have better results after primary repair and second, a study performed by Nguyen et al. (*23*), who stated that the healing process of proximal avulsion tear closely resembles that of the medial collateral ligament. DiFelice et al. performed their technique on 11 patients who had a follow-up of two years. Ten out of the 11 patients achieved a clinically stable knee and excellent reported outcome measurements (*6*). However, it is noteworthy that in the initial reports of primary repair, results of short term follow-up were also excellent but deteriorated at five year follow-up (*32,11*). In light of these findings, it will be interesting to review the results of DiFelice et al. at five years of follow-up.

CONCLUSION

The rupture of the anterior cruciate ligament is one of the most common orthopaedic injuries. A surgical solution is needed in most cases. Recent anatomic insights have shown that the ACL has a flat midsubstance. This flat configuration can also be found in its direct tibial and femoral insertion. These insights have to be implemented in future surgical approaches. ACL reconstruction remains the golden standard in surgically treating the ACL rupture. The double bundle reconstruction is favored but an individualized anatomical reconstruction should be pursued for every patient. Proper tunnel placement is key in achieving an anatomical reconstruction. Despite that it is the golden standard, ACL reconstruction has some pitfalls such as long term osteo-arthritis, functional shortcomings and variable results in a younger population. These shortcomings may be an indication for the need of a primary repair technique of the ACL. The bio-enchanced repair has been studied in animal trials and research in the future will shift towards human trials. A solely mechanical repair shows promising results as well but long term follow-up is necessary.

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