Anatomic anterior cruciate ligament reconstruction: a changing paradigm

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CHAPTER 2

DOUBLE-TUNNEL RECONSTRUCTION OF THE ANTERIOR CRUCIATE LIGAMENT

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Chapter 2: Double-tunnel reconstruction of the ACL

Abstract

Today more and more people practice a sport, causing an increase in the incidence of anterior cruciate ligament ruptures (ACL). The standard method for ACL reconstruction is single-tunnel reconstruction. However, recently there has been a growing interest in double-tunnel reconstruction. The anterior cruciate ligament consists of two functional bundles, the anteromedial and the posterolateral bundle. The anteromedial bundle provides stability of the knee during flexion and the posterolateral bundle contributes to stability during extension. Biomechanical studies have shown that double-tunnel reconstruction, reconstructing both bundles of the anterior cruciate ligament separately, better restores knee kinematics than single-tunnel reconstruction, especially during rotational forces and combined internal torque and valgus. Better restoration of knee kinematics may reduce the risk of early osteoarthritis. The first randomized controlled clinical trials comparing single- and double-tunnel reconstruction showed better short-term results after double-tunnel reconstruction. However, the long-term results of these and other studies will have to demonstrate the benefit of double-tunnel reconstruction over the current golden standard.

Introduction

Injuries of the anterior cruciate ligament (ACL) are one of the most common knee traumas in athletes. The yearly incidence is 60 out of 100,000 people. ACL injuries do not only occur in professional athletes, but also in people that participate in sports at a recreational level. Surgical reconstruction of the ACL is a frequently performed orthopaedic procedure. The goal is to restore normal knee function and stability. The golden standard technique uses a tendon autograft to reconnect the tibia and femur in one tibial and one femoral tunnel. Historically, the bone-patellar-tendon-bone graft was used almost exclusively, but due to complaints of anterior knee pain, the hamstring tendon is a good alternative showing similar outcomes and less donor site morbidity. The success rate of a conventional single-tunnel ACL reconstruction is between 90% and 95%. Return to sports is usually possible after 9 months. Despite the good results of the procedure, normal knee function is often not completely reproduced and 15-25% of the patients complain about residual instability and pain. Long-term follow-up studies show a high rate of osteoarthritis after ACL reconstruction, suggesting that the procedure does not prevent degenerative changes. Although these changes may also be caused by the initial impact during the injury and concomitant knee injuries, the results indicate that the surgical technique can be improved.

To restore the anatomy of the ACL more accurately, the double-tunnel reconstruction technique has been developed, also known as double-bundle ACL reconstruction. This technique restores both the anteromedial (AM) and the
posterolateral (PL) bundle of the native ACL, each in its own tibial and femoral tunnel. The technique was originally described by Mott in 1982 and by Zaricznyj in 1987, but Rosenberg was the surgeon who further developed the procedure. Muneta is regarded by many as the founder of the technique in its current form. The native ACL exists of two functional bundles, the AM and PL bundle. The bundles work together to provide both anterior stability and rotational stability of the knee. Biomechanical and kinematic studies have proved that double-tunnel reconstruction of the ACL better restores knee stability. The first clinical studies show favorable results of double-tunnel reconstruction as compared to single-tunnel reconstruction. However, as Eriksson discussed in his editorials, there are currently no long-term follow-up studies to determine if the double-tunnel technique decreases the risk of early osteoarthritis. This overview paper discusses the anatomy, function, imaging, biomechanics, kinematics and the surgical reconstruction of the ACL.

Anatomy and Function

Knowledge of the anatomy of the ACL is essential both for understanding the mechanism of injury and for surgical reconstruction of the ACL. Many arthroscopic and cadaveric studies have been performed on ACL anatomy. The ligament consists of fibrous tissue and is between 22 and 39 mm long, with a diameter of 7-12 mm. It has two functional bundles: the AM and PL bundle (Figure 1). These two bundles can be distinguished on the basis of anatomy, but they also have a different role in providing knee stability. The bundles derive their name from the location of their insertion on the tibia. On the femur, the AM bundle attaches more proximal on the lateral femoral condyle, whereas the posterolateral bundle is more distal. The bundles fan out on to the bone, making the insertion site 3 to 3.5 times as large in diameter as the mid-portion of the ligament.

Figure 1: The anteromedial and posterolateral bundle of the ACL. A. During arthroscopy. B. In a cadaveric specimen.
Chapter 2: Double-tunnel reconstruction of the ACL

On the tibia, the ACL has a close relationship with the lateral meniscus and the posterior cruciate ligament\textsuperscript{22, 24, 26}. In full extension the two bundles are parallel to each other, but during flexion the bundles cross each other as the PL bundle moves more anterior on the femoral side and the AM bundle loosens\textsuperscript{27, 30} (Figure 2).

![Figure 2: The tibial and femoral ACL insertion site. A. During extension. B. During flexion.](image)

Sakane et al.\textsuperscript{31} and Gabriel et al.\textsuperscript{32} studied the forces and the tension in the AM and PL bundle and found that the AM bundle has higher forces in flexion; the PL bundle forces are maximal in extension. This inversely proportional relation between length and tension of the bundles provides stability of the knee throughout the entire range of motion.

Imaging

The AM and PL bundle can be visualized by means of a 1.5 Tesla sagittal MRI sequence with a maximal slice spacing of 3 mm. When the knee is in extended position, the bundles are seen to run parallel to each other (Figure 3). The bundles can also be seen on the coronal sequence. MRI is useful to evaluate for partial ACL ruptures, such as isolated AM or PL bundle injuries. A higher resolution can be used to increase the accuracy of visualizing the two bundles (such as 3.0 Tesla)\textsuperscript{33}. However, this is more expensive and takes more time than the standard 1.5 Tesla MRI scan.
Injury

Injuries of the ACL usually occur during sports activities (Figure 4), especially during sports that put extreme forces and strains on the knee, such as soccer, hockey, basketball, gymnastics, wrestling, volleyball and skiing. Ruptures mostly happen because the ligament is stretched out too far, especially when a movement is suddenly stopped (deceleration or landing after a jump) and in twisting or pivoting motions, or when great anterior forces are exerted on the knee (a kick). The location of the rupture within the ACL depends on the mechanism of injury. Often both bundles rupture, but sometimes just one of the two. The attachment on the femur is weaker than that on the tibia.22

Figure 3: Sagittal MRI of the ACL with the AM and PL bundle.

Figure 4: ACL rupture. A. As seen during arthroscopy. B. As seen on MRI.
This is probably the reason for the higher incidence of proximal sided ruptures. Sometimes the bundles do not rupture but elongate, which leads to loss of function. Ruptures of the AM bundle are more often explosive in nature.

**Biomechanics and Kinematics**

Woo et al.\(^{35}\) showed in cadaveric studies that single-tunnel reconstruction appropriately restores the anterior stability of the knee, but not the rotational stability. This implies that the PL bundle is largely responsible for the rotational component. This hypothesis was tested by Yamamoto et al.\(^{36}\), who restored only the PL bundle in their cadaveric model. They reported restoration of rotational stability, but persistent anterior instability. A study by Mae et al.\(^{37}\) showed that both the anterior and rotational stability were superior after double-tunnel reconstruction as compared to single-tunnel reconstruction with hamstring tendon autograft.

Yagi et al.\(^{38}\) conducted a kinematic study comparing intact knees with ACL deficient knees and knees with single-tunnel or double-tunnel ACL reconstruction with hamstring tendon. They found that double-tunnel reconstruction restored normal knee kinematics more closely than single-tunnel ACL reconstruction, especially during rotation and valgus stress. Tashman et al.\(^{39}\) studied knee kinematics in vivo after conventional single-tunnel ACL reconstruction, using dynamic stereo radiography. The subjects included in the study performed downhill running on a treadmill. The anterior stability was restored sufficiently compared with the non-injured side, but the rotation of the tibia in relation to the femur had increased as compared to the non-injured side.

**Surgical Technique**

There are many techniques for double-bundle ACL reconstruction. However, these techniques do not always use a double tunnel. Some authors report using one tibial and one femoral tunnel with a doubled or split graft\(^{40-42}\). Others suggest one tibial tunnel with two femoral tunnels\(^{43}\), or one femoral tunnel with two tibial tunnels\(^{44,45}\).

![Figure 5: Attachment of the AM and PL bundle of the ACL on the tibia after removal of the soft tissue.](image)
The double-tunnel technique uses two tibial and two femoral tunnels\textsuperscript{12, 15, 37}. We will continue to describe the latter technique as performed by the senior author (FHF)\textsuperscript{46, 47}

First the ACL is inspected and the soft tissue remnants are carefully removed to expose the ACL insertion site (Figure 5). The insertion site is marked to indicate the location of the tunnels for the ACL reconstruction. When the native ACL insertion site cannot be accurately visualized, surrounding structures can be used as landmarks. On the femoral side, the lateral intercondylar ridge and lateral bifurcate ridge can be used\textsuperscript{48}, on the tibial side, the lateral meniscus and the posterior cruciate ligament. First, the femoral PL tunnel is drilled. Then both the tibial AM and PL tunnel are drilled, followed by the femoral AM tunnel. There should be a 2 mm bony bridge between the femoral AM and PL tunnel. In most cases the femoral AM tunnel can be drilled transtibially, but sometimes the medial portal is used\textsuperscript{49}. After the tunnels have been created, the grafts are routed through the tunnel; first the PL bundle and then the AM bundle (Figure 6). Suspensory fixation is used on the femoral side and interference screw fixation on the tibial side. The AM bundle is fixed at 45 degrees of knee flexion and the PL bundle in full extension.

\textbf{Figure 6:} Arthroscopic view of the position for tunnel placement during ACL reconstruction. \textbf{A.} The grafts are routed through the tunnels. \textbf{B.} The end result after the AM and PL bundle are restored.

If only one of the two bundles of the ACL is torn, the decision can be made to perform an augmentation procedure, in which only one of the two bundles is reconstructed\textsuperscript{50}. Rehabilitation after double-tunnel reconstruction is similar to that after single-tunnel reconstruction. The recovery time and physiotherapy protocols are also the same\textsuperscript{51}. 

34
Chapter 2: Double-tunnel reconstruction of the ACL

Outcomes

Most randomized studies comparing single-tunnel and double-tunnel ACL reconstruction demonstrate better outcomes for double-tunnel reconstruction. One study shows no difference between the two techniques. Adachi et al. reported on 108 patients (55 single-tunnel and 53 double-tunnel) with a follow-up of 32 months. They found no statistically significant differences for KT arthrometer side to side difference and proprioception. However, the authors did not report on IKDC score or rotational stability.

In 2007 Yagi et al. published a prospective randomized clinical study with 60 patients divided into three groups. 20 patients received double-tunnel reconstruction, 20 only AM bundle reconstruction and 20 only PL bundle reconstruction. One year after the surgery, stability of the knee was measured under anesthesia by means of the KT arthrometer. No statistically significant differences were found for anterior stability or IKDC. The pivot shift test was quantified by means of a 3D electromagnetic system. Double-tunnel reconstruction resulted in better rotational stability than reconstruction of just the AM or PL bundle.

In 2008 Jarvela et al. reported two-year follow-up results of a prospective randomized study in which 35 patients with double-tunnel reconstruction were compared to 30 patients with single-tunnel reconstruction. No difference was found for anterior stability and IKDC and Lysholm score. However, rotational stability was better after double-tunnel reconstruction.

Kondo et al. reported on a cohort of 328 subjects, 157 of whom had undergone single-tunnel reconstruction and 171 double-tunnel reconstruction. Two years after the procedures both the anterior and rotational stability were better in the double-tunnel group. There was no difference for important patient-reported outcomes measures, such as IKDC and Lysholm.

The long-term results of these and other studies will have to prove if the double-tunnel reconstruction technique remains superior to single-tunnel reconstruction as regards rotational stability and if in fact this leads to a decrease in the incidence of early osteoarthritic changes.

Discussion and Conclusion

Anatomic, imaging, biomechanical and kinematic studies have shown that the ACL is a complex anatomic structure. The ACL consists of two functional bundles and is not one isometric structure. Reconstruction of the ACL applying a single-tunnel technique restores the ACL as one bundle, whereas it really consists of two bundles. The AM bundle provides stability of the knee primarily during knee flexion, whereas the PL bundle plays an important role in extension. Research has shown that the double-tunnel technique better replicates the native ACL.
anatomy and more successfully restores knee kinematics, as compared to single-tunnel ACL reconstruction using a hamstring tendon. Therefore, some authors think that the surgical reconstruction of the ACL should focus on replicating the anatomy thereby improving the long-term outcomes of the procedure. Muneta, one of the founders of the double-tunnel technique, believes that double-tunnel reconstruction using a hamstring graft may be better than the single-tunnel hamstring technique. However double-tunnel ACL reconstruction using a hamstring graft may not be better than single-tunnel reconstruction using a bone-patellar-tendon-bone graft, as regards fixation. Especially in eastern countries, where people often kneel as part of their religious beliefs, the double-tunnel technique with hamstring graft may be better than single-tunnel reconstruction with bone-patellar-tendon-bone autograft. However, in western societies this may not be the case and single-tunnel reconstruction remains the golden standard. Moreover, for high-level athletes the loss of flexion after hamstring tendon harvest may present problems.

In their editorial Harner and Poehling asked if the (theoretical) advantages of double-tunnel reconstruction outweigh the potentially higher rate of complication of a technically more demanding and also more expensive procedure with which many low-volume surgeons are still unfamiliar. Furthermore, a large variety of double-tunnel reconstruction techniques is used. The most important difference lies in the drilling method of the femoral tunnels: transtibial or medial portal. Medial portal drilling may lead to a more anatomic position, which results in a better outcome. As Lubowitz and Poehling recently wrote: the A (anatomy), B (biomechanics) and C (clinical) of a new operative procedure has to show if the procedure is better than the current golden standard. This also applies to ACL surgery. If this is the case for double-tunnel reconstruction, long-term follow-up results will have to demonstrate. For the non-kneeling patient in western countries the single-tunnel bone-patellar-tendon-bone technique still remains a good alternative.

References

Chapter 2: Double-tunnel reconstruction of the ACL


Chapter 2: Double-tunnel reconstruction of the ACL

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