CURRENT CONCEPTS REVIEW

Anatomical Individualized ACL Reconstruction

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Abstract

The anterior cruciate ligament (ACL) is composed of two bundles, which work together to provide both antero-posterior and rotatory stability of the knee. Understanding the anatomy and function of the ACL plays a key role in management of patients with ACL injury. Anatomic ACL reconstruction aims to restore the function of the native ACL. Femoral and tibial tunnels should be placed in their anatomical location accounting for both the native ACL insertion site and bony landmarks. One main component of anatomical individualized ACL reconstruction is customizing the treatment according to each patient’s individual characteristics, considering preoperative and intraoperative evaluation of the native ACL and knee bony anatomy. Anatomical individualized reconstruction surgery should also aim to restore the size of the native ACL insertion as well. Using this concept, while single bundle ACL reconstruction can restore the function of the ACL in some patients, double bundle reconstruction is indicated in others to achieve optimal outcome.

Keywords: Anatomic ACL reconstruction surgery, Anterior Cruciate Ligament, Individualized medicine

Introduction

Anterior cruciate ligament injury (ACL) is one of the most common ligamentous lesions of the knee. ACL injury is associated with increased risk of menisci and cartilage degeneration, and future development of osteoarthritis (1, 2). The management of these injuries is generally either non-operative rehabilitation or surgical reconstruction. The decision to perform reconstruction surgery is based on the presence of concomitant injuries, the patient’s subjective and objective sense of instability, and the desired level of physical and sports activity. This article will focus on the surgical treatment of these patients with special focus on the concept of anatomical individualized ACL reconstruction.

Anatomy and Function of the ACL

The ACL is the primary structure that moderates anteroposterior and rotatory stability of the knee, especially in lower flexion angles (3). ACL is composed of two bundles, the anteromedial (AM) and posterolateral (PL) bundles, which are named based on their respective insertion location on the tibia. The femoral insertion of the ACL is oval shaped and is usually smaller than the fan shaped tibial insertion site [Figure 1]. There are two prominent osseous ridges on the lateral wall of intercondylar notch that denote the borders of the femoral ACL insertion site: the lateral intercondylar ridge marks the anterior border of the ACL, and the lateral bifurcate ridge runs perpendicular to the lateral intercondylar ridge and separates the femoral attachment of the AM and PL bundles (4).

The AM and PL bundles work together as a unit to provide both anterior stability and rotation stability of the knee in response to complex loads throughout the entire range of knee motion. More specifically, the PL bundle plays a more prominent role in controlling antero-posterior stability and rotation in lower flexion angles (5). The aim of ACL reconstruction surgeries is to restore the function of the both bundles in order to reestablish the dynamic stability of the knee joint.

Non-operative treatment

There is a group of patients with ACL injury generally referred as “copers” that can asymptotically return to pre-injury level of activity without reconstruction surgery. It has been demonstrated that these patients have...
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Fig 1. Femoral insertion of the ACL, the “AM” and “PL” denotes the corresponding insertion of posterolateral (PL) and anteromedial (AM) bundle of the ACL. LFC: lateral femoral condyle.

functionality of the remaining fibers. Preserving the intact during arthroscopic examination can help to determine the laxity before surgery and careful probing of the remnants reconstruction of the injured bundle. Evaluation of joint surgery can be considered by focusing attention on exclusive Augmentation Reconstruction Surgery

Anatomic ACL Reconstruction Concept

Traditional ACL reconstruction surgeries were performed non-anatomically by placing the graft outside of the native insertion of the ACL. The anatomic ACL reconstruction concept asserts that the native ACL must be restored following four fundamental principles: (1) restore the two functional bundles of AM and PL, (2) restore the native insertion sites of the ACL by placing the tunnels in the true anatomic positions by appropriate sized graft, (3) correctly tension each bundle according to knee flexion angle, (4) individualize surgery for each patient considering specific anatomy and needs of each patient.

Augmentation Reconstruction Surgery

If the ACL is partially injured, augmentation reconstruction surgery can be considered by focusing attention on exclusive reconstruction of the injured bundle. Evaluation of joint laxity before surgery and careful probing of the remnants during arthroscopic examination can help to determine the functionality of the remaining fibers. Preserving the intact bundle during augmentation surgery may have benefits over complete reconstruction, such as maintaining proprioceptive fibers, increasing biomechanical strength, and enhancing biological healing potential (11, 12). However studies with long term follow-up are needed to assess the outcomes of these patients (13).

Single Bundle or Double Bundle Reconstruction Surgery

As noted above, one of the main elements of anatomic reconstruction surgery is to restore the native ACL insertion site. Using a single reconstruction technique such as single- or double-bundle ACL reconstruction for all patients regardless of the circumstances is not recommended due to variation of anatomy and injury pattern between individuals. One recent study demonstrated that single bundle reconstruction surgery restores only 70-79% of the native ACL insertion size (14). The need to restore the bulk of the native ACL size is supported by previous reports that showed higher rate of reconstruction failure with smaller grafts (15).

The decision making flowchart in management of ACL injured patients has been previously described in detail (16). Generally, double bundle reconstruction surgery is considered if the patient has a large tibial insertion site size (anteroposterior length >14 mm), large intercondylar notch (length and width >14 mm), absence of concomitant ligament injuries, absence of concomitant arthritic changes (Kellgren Lawrence grade <3), absence of severe bone bruising, and closed physes (16-18). The SB technique is indicated for small tibial insertion sites (<14 mm in length), narrow notches (<12 mm in width), multi-ligamentous injuries, severe bone bruising, severe arthritic changes (grade 3 or higher) and open physes.

Several biomechanical studies report better restoration of knee kinematics with double bundle reconstruction surgery compared to single bundle reconstruction surgery (19-21). In 2012, Hussein et al. performed a prospective randomized clinical trial in ACL injured patients and followed them for a mean period of 51.15 months (22). It was revealed that anatomical double bundle reconstruction surgery results in better restoration of anteroposterior and rotational laxity compared to anatomic single bundle reconstruction. Meta-analysis of clinical studies also support that double bundle reconstruction surgery provides better antero-posterior stability and mid-term outcome scores compared to single bundle reconstruction surgery, however long-term outcome of these patients still need to be determined (23, 24). It should be noted that prospective studies demonstrated no difference among single or double bundle reconstruction techniques in terms of restoration of the anteroposterior and rotational laxity when patients are individually assigned to treatment groups based on the size of the ACL native insertion site and the intercondylar notch width (25). These findings further emphasize the need for individualized treatment of patients.

Reconstruction Technique

Portals

Three-portal approach is used during reconstruction
surgery: 1) anterolateral (AL) portal, 2) anteromedial (AM) portal and 3) accessory medial portal (AMP) [Figure 2] (26). The AL portal is positioned 1cm lateral to the patellar tendon and at the level of inferior pole of the patella. The AL portal should be high enough to avoid the Hoffa’s fat pad. The AM portal is aimed towards the central portion of the notch in the coronal plane and in the lower third of the notch in the proximal to distal direction. Application of a spinal needle under arthroscopic visualization could help in correct placement of AM portal. The AMP should be positioned superior to the medial joint line, approximately two centimeters medial to the medial border of the patellar tendon. Once again, the use of a spinal needle is essential for the placement of the AMP. There should be about 2 mm distance between spinal needle and lateral femoral condyle to avoid any injury during instrumentation. The visualization through AMP removes the need for notchplasty. Indeed, surgeons are advised not to perform notchplasty, as it will remove the important anatomical landmarks needed for tunnel placement. Furthermore, there is possibility of regrowth and overgrowth of the notch after notchplasty, which may result in abnormal forces on the graft, which eventually may cause reconstruction failure.

While AMP provides the best visualization of the native ACL insertion sites, all portals are utilized to obtain a complete view of the ACL origin and insertion sites. During majority of the surgery however, AMP portal is used for instrumentation and allows the AM portal to be used for visualization of the lateral wall of the intercondylar notch and the femoral insertion site.

**Graft Selection**

The typical grafts available for ACL reconstruction surgery include patellar tendon autograft, quadriceps tendon autograft, hamstrings tendon autograft and different kinds of allograft (27-29) [Table 1]. Of these options the bone-patellar tendon-bone graft cannot be used for double bundle reconstruction surgery. The graft of choice is individually selected based on age, gender, type and level of activity, desired time of return to sport and the preoperative measurement of native ACL insertion size.

Thickness of the quadriceps and patellar tendon measured preoperatively on sagittal MRI can guide surgeons in this regard(30). The graft healing time also differs among different types of the grafts; therefore
Disadvantages:
- Bone to bone healing
- Soft-tissue healing
- Graft size can be unpredictable
- Not suitable for certain athletes who rely heavily on their hamstring muscles
- Less stiffness than native ACL

Tunnel Placement
Technical errors including non-anatomical tunnel placement and inadequate fixation technique are among the main reasons of graft failure after reconstruction surgery (34). Improper placement of the tunnel can affect the amount of the forces that the graft will experience after reconstruction surgery (35). During reconstruction surgery the remnants of the native ACL and bony ridges of the lateral intercondylar notch (lateral intercondylar ridge and lateral bifurcate ridge) are important landmarks in identifying the tunnel positions (36, 37).

If double bundle reconstruction is indicated, the femoral and tibial tunnels are created on the respective insertion site of the AM and PL bundles [Figure 4]. The drilling tunnels starts with femoral tunnel of the PL bundle through AMP. Then the tibial AM and PL tunnel are drilled with the tibial guide set at 55° and 45°, respectively. The distance between AM and PL bundle tunnels on the tibial extra articular cortex should be at least 2 cm to allow for a bony bridge. Finally the femoral tunnel of the AM bundle is drilled through the AMP.

If single bundle reconstruction is planned, the femoral tunnel is drilled at the center of the femoral insertion site, midway between the AM and PL bundles. Likewise the tibial tunnel is drilled at the center of the tibial insertion site, midway between the center of the AM and PL insertion sites, with the tibial guide set at 55°.

Graft Fixation
Soft tissue grafts are typically fixed by application of suspensory devices in the femoral side. Although suspensory device have higher load to failure and stiffness compared to interference screws, the clinical outcome for both devices have been reported to be comparable (38, 39). Biomechanical studies however, have reported different mechanical properties among suspensory devices (40). Femoral site fixation of grafts with bone plugs is commonly accomplished with metal or bioabsorbable interference screws. Metal interference screws have been suggested as the standard fixation method with bone-patellar tendon-bone autograft (41). Fixation of the tibial site of the graft is typically performed by application of interference screws (most commonly bioabsorbable screws) due to ease of insertion and minimal slippage of the graft.

There is still no standard protocol regarding pretensioning or preconditioning of the graft, nor does consensus exist regarding the amount of tension during the graft fixation (42, 43). The knee flexion angle for graft fixation is determined with respect to the tension pattern of the native ACL. However there is no consensus in the current literature regarding knee flexion angle for fixation of the graft. For single bundle reconstruction, the graft is generally fixed at 0-20° of knee flexion (44).

Extra-articular reconstruction surgery
Recent reports regarding presence of a distinct ligamentous structure in the anterolateral capsule area or anterolateral ligament (ALL), have fueled surgeons to perform extra-articular reconstruction surgeries in addition to intra-articular ACL reconstruction. However, the anatomical characteristics and biomechanical function of this structure have been debated (45-48). Two recent meta-analysis that compared isolated ACL reconstruction with combined extra-articular tenodesis (EAT) and ACL reconstruction reported decreased laxity for combined EAT patients; however, no difference was found in functional outcomes or return to play (49, 50). It has been demonstrated that a potential risk

<table>
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<tr>
<th>Graft Options</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Patellar Tendon</td>
<td>Bone to bone healing, Large graft</td>
<td>Risk of patellar fracture, Risk of disease transmission</td>
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<tr>
<td>Quadriceps Tendon</td>
<td>Large graft, Option of a one-sided bone block</td>
<td>Invasive, large incision, Risk of patellar fracture</td>
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<td>Hamstring</td>
<td>Ease of harvest, Cosmesis, Minimal donor site morbidity</td>
<td>Soft-tissue healing, Graft size can be unpredictable, Not suitable for certain athletes who rely heavily on their hamstring muscles</td>
</tr>
<tr>
<td>Allograft</td>
<td>No donor site morbidity, Available in various types and sizes, Shortens operative time</td>
<td>Risk of disease transmission, Risk of graft-tunnel mismatch, Risk of patellar fracture, Increased risk of rerupture in irradiated allografts, especially in younger patients (10, 29, 59, 60)</td>
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Table 1. Graft options for Anatomic ACL Reconstruction (27-29)
with EAT involves over-constraining knee range of motion in respect to internal rotation (51-53). Indeed, several studies revealed that ACL reconstruction over-constrains the internal rotation of the knee during in vivo activities (54). These findings further criticize the logic of enhancing an additional restraint to the lateral side of the knee. Therefore the decision to perform additional extra articular reconstruction surgeries should be carefully made until greater consensus is achieved with future research.

Future directions
Development of clinically applicable devices to quantify rotatory laxity has the potential to improve the management of patients with ACL injury (55, 56). Employing these technologies, a cohort of ACL injured patients demonstrated wide range of kinematics during rotatory laxity testing (57). These findings support previous findings from more classic articles regarding the presence of a specific “envelope of motion” in each patient (58). Quantification of rotatory laxity in ACL injured patients could help in assigning patients to different treatment groups as well as screening the healing during post-operative rehabilitation. Future studies need to be performed to improve treatment protocols based on quantitative rotatory laxity measurements.

References

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