Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction

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Over the past decade, intense research of the function of the 2 distinct bundles, the anteromedial and posterolateral, of the anterior cruciate ligament (ACL) has led to pronounced changes in the technical concepts of ACL reconstruction. Recently, the renewed focus of ACL reconstruction has been to restore the anatomy of the ACL to its native dimensions, collagen orientation, and insertion sites. The goal of ACL reconstruction is to restore normal knee kinematics, to enable patients to return to their preinjury level of activity, and to prevent further degenerative changes of the articular knee cartilage.

Anatomic double-bundle ACL reconstruction has recently gained popularity as a concept that can be used to achieve these goals. This article provides an overview of the anatomy and function of the ACL. Furthermore, we highlight individual anatomic considerations as they pertain to ACL reconstruction and describe the technique for anatomical ACL reconstruction.

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Years of the anterior cruciate ligament (ACL) are among the most common ligamentous knee injuries, with >200,000 ACL tears occurring annually in the United States alone.1 Traditionally, conventional single-bundle (SB) ACL reconstruction was the treatment of choice for complete ACL tears; this technique improved knee stability and allowed a return to sports at short-term follow-up.2 However, several prospective series and meta-analyses have shown that a significant number of patients have persistent knee instability, which prevents them from returning to sport and their previous level of activity.3,4 After SB ACL reconstruction, good to excellent results were achieved in only 60% of patients, and <50% of patients returned to athletics at their preinjury level. Furthermore, long-term evaluation has revealed rates of osteoarthritis after SB ACL reconstruction that are similar to those in the nonoperated knee, suggesting that conventional SB ACL reconstruction does not protect the knee from degenerative changes associated with the initial ACL injury.5

Traditional SB ACL reconstruction techniques have focused on recreating the ACL as 1 ligament. Furthermore, SB reconstructions have often resulted in nonanatomic tunnel placement; the most common scenario being a tibial posterolateral (PL) position to a femoral “high antero-medial” tunnel position.6,7 Recent focus on recreating the native anatomy of the ACL has changed our approach away from the traditional ACL reconstruction technique.

Since 1938, anatomical studies have shown that the ACL consists of 2 distinct functional bundles: the anteromedial (AM) and the PL bundle8 (Fig. 1). Reconstruction of both bundles for ACL reconstruction led to the use of the term “double-bundle” when describing this technique. “Double-bundle” (DB) means that the ACL is reconstructed using 2 separate bundles but does not specify the location of tunnel placement. However, the term “anatomic” differs from the term “double-bundle,” implying that the ACL graft is placed in the anatomic position with the tunnels drilled into the native ACL insertion site, regardless of the reconstruction technique (SB vs DB).
The goal of ACL reconstruction is to restore normal knee kinematics, to enable patients to return to their preinjury level of activity, and to prevent further degeneration of articular knee cartilage. Anatomic DB ACL reconstruction has recently gained popularity as a technique that can be used to achieve these goals.

Anatomy and Biomechanical Considerations

Anatomy is the basis of orthopedic surgery. The approach to ACL reconstruction should be governed by this concept, aiming to reproduce the native anatomy and physiological function of the knee. The ACL consists of 2 functional bundles, named according to the relative position of their tibial insertions: the AM bundle and the PL bundle. On the femoral side, the bundles are vertically aligned with the knee in full extension, with the AM insertion superior to the PL insertion. When the knee is flexed to 90° during surgery, however, the bundles are horizontally aligned, with the AM insertion site relatively deeper in the knee joint than the PL insertion site. Both bundles have a synergistic but distinct biomechanical function throughout the range of motion of the knee. In full extension, the PL bundle is taut, and the AM bundle is more lax. During knee flexion, the femoral insertion site becomes horizontal, resulting in the tightening of the AM bundle and loosening of the PL bundle. The independent kinematic function of each bundle has important clinical implications. Biomechanical studies have shown that DB ACL reconstruction restores the knee function closer to preinjury levels, particularly with internal and external rotation, than the conventional SB reconstruction procedure.9 Each bundle serves an integral purpose to prevent abnormal knee biomechanics as a function of knee flexion angle. The AM bundle is the primary restraint against anterior–posterior translation, whereas the PL bundle is primarily responsible for rotational stability.10 Therefore, by recreating the native anatomy, the concept of anatomic DB ACL reconstruction may restore preinjury kinematics.

To reconstruct the ACL anatomically, detailed knowledge of the anatomical bony landmarks of the femoral and tibial insertion sites is essential. On the femoral side, 2 bony landmarks on the lateral wall of the intercondylar notch are the most important. The lateral intercondylar ridge, or “resident’s ridge,” represents the anterior border of the femoral AM and PL bundle insertion sites when the knee is flexed to 90°. The second ridge, the lateral bifurcate ridge, which is present in 80% of all cases, separates the origins of the AM and PL bundle insertion sites and runs perpendicular to the lateral intercondylar ridge11 (Fig. 2). Knowledge of these landmarks is crucial to anatomical restoration of the ACL, especially in chronic cases where the bundle remnants may have completely resorbed.

The Concept and Indications of Anatomic DB ACL Reconstruction

Anatomic DB ACL reconstruction is not merely a technique but rather a concept based on the following 4 principles. The first concept involves restoration of both the AM and PL bundles. Second, the tibial and femoral tunnels should be placed anatomically within their native ACL insertion sites. Third, each bundle is tensioned in accordance with its native tensioning pattern from full knee extension through flexion. The fourth and final principle is to customize the surgery for each patient by taking into account their respective ACL insertion anatomy and activity level.
Several studies have shown that the variation in ACL insertion site anatomy may allow surgeons to determine whether an SB or a DB ACL reconstruction should be performed. A small native tibial insertion site (<14 mm) may not allow for DB ACL reconstruction, and a larger insertion site (>18 mm) may be insufficiently restored if an SB technique is used. Furthermore, a small notch width (<14 mm) may not allow for placement and drilling of the tunnels at the native insertion site without damaging the medial femoral condyle (Fig. 3). Additional contraindications for anatomic DB ACL reconstruction include patients with open physes, multiligamentous knee injuries, and/or severe subchondral bone bruising, especially if bruising is located on the lateral femoral condyle. In these specific scenarios, an SB ACL reconstruction is performed.

Recently, Hussein et al. found no significant differences between SB and DB reconstructions for all subjective and objective clinical outcome measures when using an individualized approach. The decision for using the DB ACL reconstruction technique can therefore be made using the patient’s anatomical variation and lifestyle considerations.

Preoperative Planning

The first step in diagnosing ACL injuries is to obtain a detailed history and to perform a thorough physical examination. Comparing the injured knee with the contralateral non-injured knee is obligatory to provide an estimate of the patient’s normal knee function and stability.

High-resolution magnetic resonance imaging is the gold standard for evaluating ligamentous, meniscal, and chondral injury. Although the ACL can be visualized with T1- or T2-weighted images on “standard” views in the coronal and sagittal planes, clearly discriminating the AM and PL bundles may be difficult. Visualization is enhanced by obtaining special MRI in the oblique coronal and oblique sagittal planes. These views are acquired by cutting MRI sections in the same anatomical alignment as the ACL, which allows a clear and predictable recognition of partial ACL tears.

Decisions about the components of the future surgery, such as graft choice and SB vs DB technique, are made based on findings and measurements from the magnetic resonance images. As mentioned previously, the decision to perform anatomic DB ACL reconstruction depends on individual anatomy and associated measurements. These measurements include tibial insertion site length (normal range: 9-25 mm), inclination angle (normal range: 43-57°), ACL length (normal range: 25-45 mm), and thickness of the quadriceps and patellar tendons on views in the sagittal plane. For instance, if the tibial insertion site measures <14 mm, drilling 2 separate tunnels may not be technically safe because of the inability to maintain a 2-mm bone bridge between them. In these cases, an SB reconstruction would likely yield the best anatomic reconstruction.

Unfortunately, deciding which technique should be used is not based solely on the measurements of the tibial insertion site; cofactors such as the intercondylar notch size should also be taken into account, especially when the tibial insertion site length ranges between 14 and 18 mm. To date, it remains unclear which technique yields the best results when the tibial insertion site measures within this range, and either an anatomic SB or a DB reconstruction may be performed. Consequently, the ultimate decision to do an SB or a DB ACL reconstruction is best made intraoperatively.

Anatomic ACL Reconstruction—Surgical Technique

The patient is positioned supine with the operative leg in the leg holder and a tourniquet placed on the proximal thigh. The contralateral extremity is positioned out of the surgical...
field in the lithotomy position. Positioning of the operative extremity is carefully performed to allow for >120° of knee flexion.

First, an examination under anesthesia is performed to evaluate for associated ligamentous laxity: Lachman, anterior drawer, posterior drawer, AM and PL drawer, and dial test examinations at 30 and 90° of knee flexion are performed on the affected and contralateral sides. If the patient has a known unstable meniscus tear (ie, bucket handle tear) in association with an ACL tear, the pivot shift should be deferred.

A clear visualization of the native insertion sites is of the utmost importance for anatomic ACL reconstruction. Therefore, a 3-portal approach has been shown to provide the best visualization of both the tibial and femoral insertion sites15 (Fig. 4). A “high” anterolateral portal (LP) is created above Hoffa’s fat pad, thus minimizing the need to traverse the fat pad and allowing for superior evaluation of the tibial insertion site. The central portal (CP) is then established under direct visualization through the LP using a spinal needle, as position may vary based on the patient’s individual notch orientation. This portal, which is located just above the level of the meniscus, provides 3-dimensional visualization of the intercondylar notch and the medial wall of the lateral femoral condyle. In establishing this portal, great care is taken to protect the intermeniscal ligament. Spinal needle guidance is again used to create the medial portal (MP), which should be placed above the medial meniscus and provide direct access for the guidewire and reamer to the femoral native insertion site. Because this portal is positioned close to the medial femoral condyle, careful attention must be paid to its trajectory to avoid iatrogenic damage to the cartilage.

Diagnostic arthroscopy is then performed to confirm the rupture pattern of the ACL and to evaluate for concomitant intra-articular pathologies. The remnants of the ACL are then carefully dissected using a shaver and thermal device to expose and mark the native insertion sites of the AM and PL bundles. Viewing from the LP and CP, measurements are obtained of the tibial and femoral native insertion site length, mid-width, and individual bundle-widths with an arthroscopic bendable ruler (Smith & Nephew Endoscopy, Andover, MA). Measurements of the notch are then taken, documenting width at the base, the middle and the apex, as well as the height on the medial and lateral side. After all measurements are documented, the decision whether to perform anatomic SB or DB ACL reconstruction can be made.

The following sections describe the technical considerations for both anatomic SB and DB reconstruction for varying graft choices. Despite the nomenclature of “single-bundle” and “double-bundle,” each technique is performed according to a “double-bundle” concept. This concept implies that each native ACL is a DB and that adequate restoration of the native size, shape, and orientation of the ACL, by either SB or DB reconstruction, will result in a reconstruction of both bundles.

**DB Reconstruction With Quadriceps Tendon With Bone Block**

In DB ACL reconstruction, using the quadriceps tendon with bone block (Fig. 5), the femoral tunnels are prepared first. A thermal device is used to identify both the AM and PL insertions, which will be landmarks that are used for anatomically positioning the femoral tunnels. These soft-tissue remnants, along with bony anatomy, provide a clear and accurate visualization of the femoral insertion site. Recognizing landmarks such as the lateral intercondylar ridge and the bifurcate ridge may be useful for identifying the individual bundle insertions, especially in chronic cases where the soft tissue may have already partially resorbed.11

![Figure 4](image-url) The 3-portal approach in a right knee in 90° of flexion: central portal (CP), “high” anterolateral portal (LP), and medial portal (MP).

![Figure 5](image-url) An autogenous quadriceps tendon graft with bone block. The tendon was split to create an AM and PL bundle.
Next, while viewing through the MP, measurements of the femoral insertion site are made with an arthroscopic ruler (Fig. 6). For a DB reconstruction using a quadriceps tendon graft with a bone block, a single femoral tunnel and 2 tibial tunnels are created (Fig. 7). The femoral tunnel is positioned midway between the AM and PL insertion sites with a Steadman awl for the guidewire to follow with subsequent advancement through the lateral cortex. The distance from the medial wall to the lateral cortex and the desired tunnel dimensions are then determined. The femoral tunnel is reamed to a depth of at least 20 mm and dilated to allow for graft passage while maintaining the tightest possible fit. A suspensory device drill is used to breach the far lateral cortex. Traditionally, rigid guidewires and reamers are used to place and drill the tunnels; however, this instrumentation often requires knee hyperflexion to avoid iatrogenic damage to nearby structures. Oftentimes, flexible reamers may be desired, as these devices do not require knee hyperflexion; moreover, they decrease susceptibility for posterior cortical violation by altering the drill exit point and an increase in tunnel length (Fig. 8).

Attention is then turned to the tibial side. The tibial insertion site is carefully dissected with a thermal device, and the PL and AM insertion sites are marked. A vertical incision of 3-4 cm is made along the proximal AM aspect of the leg, between the anterior tibial tubercle and the medial tibial crest. A tibial tip-to-tip guide is set to 45° and placed in the center of the PL bundle, and a guidewire is then advanced. Another guidewire is similarly advanced to the center of the AM insertion with the guide now set to 55°. To ensure an adequate bone bridge between the tunnels, the tunnel

![Figure 6](image1)  
**Figure 6** Arthroscopic view through the MP. Measurements of the femoral insertion site length (A) and height (B) are made with an arthroscopic ruler.

![Figure 7](image2)  
**Figure 7** A central femoral tunnel after drilling. The dilators are left in the 2 tibial tunnels for a better illustration.

![Figure 8](image3)  
**Figure 8** A flexible reamer.
trance should be 2-cm apart on the tibial extra-articular cortex, and intra-articular pin spread should be at least 12 mm (Fig. 9). To ensure that no notch impingement is presented, the knee is then brought into full extension. The relationship between the K-wire and the roof of the intercondylar notch should be evaluated with the knee in full extension to avoid potential impingement of the ACL graft.

After drilling the tunnels, the tunnel aperture can be measured with the arthroscopic ruler. By calculating the area of both the native insertion site as well as the tunnel aperture using the formula of an ellipse, the percent reconstructed area can be calculated. Given limitations associated with the currently available instrumentation and graft options, the goal should be to restore at least 60%-80% of the native insertion site area.

The graft is passed next. The bone block with suspensory device is passed through the MP and positioned within the femoral tunnel. Confirmation of suspensory fixation outside of the lateral cortex is obtained with fluoroscopy. Attention should be paid to the orientation of the bone block, as the soft-tissue portion is split into PL and AM grafts that should be positioned accordingly. Flexible loop wires are passed retrograde through the AM and PL tibial tunnels and retrieved through the CP. The sutures from the AM and PL soft-tissue grafts are then retrieved and pulled through the tibial tunnels. Under arthroscopic visualization, the PL graft is passed first, followed by the AM graft, to ensure appropriate placement relative to one another. The knee is then cycled several times with tension applied to the tibial ends of the grafts. Finally, on the tibial side, the PL bundle is first fixed at 0° and the AM bundle at 45° of knee flexion to approximate the native tensioning pattern (Fig. 10).

**DB Reconstruction With Soft-Tissue Grafts**

Although the quadriceps graft is regarded as the most vigorous available in terms of healing potential,17 some patients may prefer another graft type. For DB reconstruction, soft-tissue grafts provide an alternative to bone-tendon grafts. Because separate soft-tissue grafts are used for the AM bundle and PL bundle, separate femoral AM and PL tunnels should be drilled (Fig. 11). In these cases, the PL tunnel is prepared first through the MP and positioned in the center of the PL insertion. The tibial tunnels are then prepared, in a similar fashion as described in the previous section, before drilling the femoral AM tunnel. Depending on individual anatomy and surgical preference, the femoral AM tunnel may be drilled with a transtibial or MP technique. Rarely can the tibial AM tunnel be used (~10% of cases), but, frequently, the tibial PL tunnel can be used (~50%), and nearly always, the MP can be used (>95%). After establishing the tunnels, percent reconstructed area may be calculated in a similar fashion as described previously.

Before passing the grafts, a beath pin is passed through the femoral tunnels and the suture loop is retrieved through the tibia PL and AM tunnels, respectively. To ensure appropriate placement of each passing suture, arthroscopic examination is performed. The PL graft is passed through the tibial tunnel and into the femoral tunnel before AM graft passage. Correct positioning of suspensory fixation outside the lateral femoral cortex is confirmed before graft tensioning. Fixation at full extension for the PL graft and at 45° of flexion for the AM graft is performed.

**Figure 9** After the 2 tibial pins are placed at the native insertion site, measurements are taken to confirm an adequate bone bridge between the tunnels.

**Figure 10** Final result after anatomic double-bundle ACL reconstruction using an autogenous quadriceps tendon graft and bone block (LFC, lateral femoral condyle).
SB Reconstruction

Anatomic SB reconstruction is performed according to a similar algorithm as previously described for the DB procedure, with a few differences. One femoral tunnel and 1 tibial tunnel are positioned midway between the AM and PL insertion sites (Fig. 12). Also, after graft passage, this singular graft is fixed at 15° of knee flexion.

As previously discussed, ACL reconstruction using an SB graft should always be performed according to the native DB concept. Practically, this means that the graft is carefully positioned in the tunnels with a designated PL and AM portion. The PL portion of the graft is marked before graft passage. The graft is oriented to allow for this portion to be located in the PL position on the femoral and tibial sides. By anatomically positioning the fibers within the femoral and tibial insertions, an SB reconstruction can be performed while applying the DB philosophy/concept.

Rehabilitation

Anatomic SB and DB ACL reconstruction techniques follow the same rehabilitation protocol, as previously described. The initial goal of rehabilitation is the control of pain and swelling followed by early restoration of full passive knee extension. Other essential goals include regaining full range of motion and quadriceps strength. However, to prevent graft failure, a careful planning of the postoperative rehabilitation program is of great importance. Patients should be informed that although anatomic ACL reconstruction provides superior kinematics and may lead to improved long-term health of the knee, the graft still needs time to remodel and heal. Furthermore, because of the anatomic placement of the graft, it is subject to greater forces throughout rehabilitation at an average of 9 months, patients are typically allowed to return to sports. However, sport-specific training drills may be initiated between 6 and 7 months postoperatively. Patients may feel healthy and prepared to return to previous activities earlier than this time frame, but one should resist the temptations of more aggressive rehabilitation programs and thus possible graft failure.

Conclusions

Anatomic bundle-specific techniques allow for the customization of surgery to each patient, accounting for anatomical and functional differences. These techniques, and a rehabilitation protocol that considers healing and remodeling, provide the patient with the greatest potential for a successful clinical outcome. Currently, evidence is mounting that anatomic bundle-specific reconstruction techniques lead to better knee kinematics and possibly to subsequent prevention of the early onset of degenerative changes of the knee joint.

References


