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Anterior Cruciate Ligament Reconstruction: A Literature Review of the Anatomy, Biomechanics, Surgical Considerations, and Clinical Outcomes

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Anterior cruciate ligament (ACL) ruptures are some of the most common knee injuries seen by sports medicine physicians. However, given the complex anatomy and function of the ACL, reconstruction of this ligament is anything but straightforward. The last decade has seen much advancement in ACL reconstruction, with an improved knowledge of the biology and biomechanics of graft incorporation, new choices for graft material and graft fixation devices, and more accelerated rehabilitation protocols. Although there are numerous studies in the literature on ACL reconstruction, there is yet to be a consensus among surgeons on the "best" graft choice and the "optimal" fixation device. This is generally attributed to the small sample size in most studies, which prohibits a definite conclusion of superiority of one technique over another. Additionally, it is difficult to directly compare the results from one study to another because there is tremendous heterogeneity between studies. This review is intended to examine the anatomy, biomechanics, surgical considerations, and clinical outcomes after ACL reconstruction that have been highlighted in the literature during the past 10 years.
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The integrity of the anterior cruciate ligament (ACL) is important to athletes who participate in running, cutting, and jumping sports. While some athletes can continue to participate in their sport after an ACL injury, many require reconstruction. Although an improvement in function can be achieved by current techniques of ACL reconstruction, the biologic and physiologic characteristics of the normal ACL are not fully restored.

There are many surgical considerations when planning ACL reconstruction. Currently, most ACL reconstructions are performed with bone–patellar tendon–bone (BPTB) or hamstrings autograft. However, there has been recent interest in the use of allograft tissue given the early reports of good outcomes and less donor site morbidity.[1-4] In addition to graft choice, other areas under current investigation are graft fixation and graft tensioning. Although our understanding of the biology and biomechanics of graft incorporation have improved, the initial stability of the graft is dependent on the fixation method. Therefore, for the knee to withstand the increased activity associated with modern rehabilitative protocols, initial fixation strength is critical. In this work, we have reviewed the recent literature on graft incorporation, graft choice, and fixation as well as the clinical outcomes after ACL reconstruction that have been reported from 1994 through the present to help clarify the extensive and sometimes confusing data on this topic.

Anatomy and Biomechanics

Optimal evaluation and management of the ACL hinges on a thorough understanding of ligament anatomy and function. The complexities of ACL anatomy and physiology have been debated in the literature, and various authors have offered a

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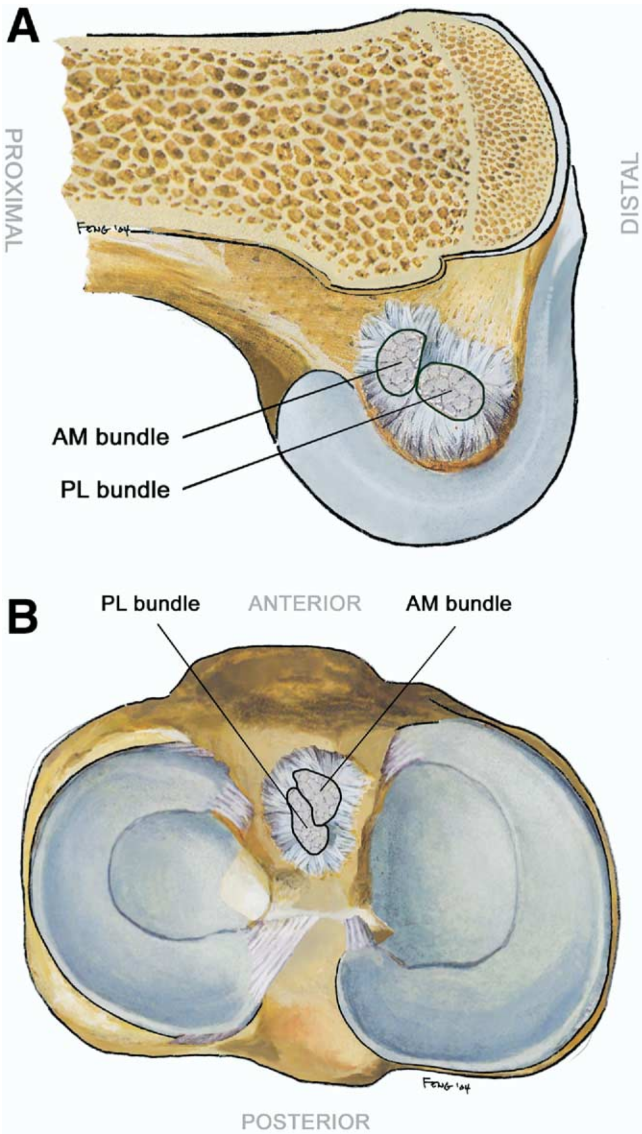

Figure 1 (A) Schematic drawing of medial aspect of the lateral femoral condyle illustrating the femoral attachment of the anteromedial (AM) and posterolateral (PL) bundles of the anterior cruciate ligament (ACL) in the sagittal plane. (B) Schematic drawing of the tibial plateau illustrating the tibial insertion of the AM and PL bundles of the ACL in the axial plane.

diverse array of concepts, nomenclature, and reconstructive techniques. In 1938, Herzmark described the cruciate ligaments as vestigial structures,[5] whereas Hey Groves and others advanced the cruciates as major knee stabilizers.[6-9] Nearly a century later, we have come to agree on the basic anatomy and biomechanics of the ACL.

Gross Anatomy

The ACL runs from the posteromedial aspect of the intercondylar notch on the lateral femoral condyle to a triangular space on the tibia between the medial intercondylar eminence and the anterior horns of the menisci (Fig. 1). Grossly, the femoral attachment has been described as planar[10] or concave,[11-13] and its projection as semicircular,[12,14] ovoid,[13,15] or circular.[16] The ligament's posterior border is a convex arc complementing the curvature of the condyle's articular surface, whereas the anterior border has a less predictable contour. The ligament fans out[10,17,18] from its relatively narrow midsubstance to insert on the femur over an average area of 113 to 170 mm^2.[12,15,16] Multiple studies have identified separate bundles of the ACL.[11,12,14,18-20] The more proximal anteromedial (AM) bundle comprises 49% of the femoral footprint, whereas the more distal posterolateral (PL) bundle accounts for the remaining 51%.[16] The tibial attachment consists of a wide, oval fossa[14] covering a mean area of 136 to 150 mm^2.[15,16] The fan-shaped tibial attachment has been found to be both larger and stronger than the femoral.[12,14] The AM and PL bundles are named after their tibial attachments; the AM is anterior and medial to the PL. An intermediate bundle has also been described and is depicted as being anterolateral.[21]

Between the femur and tibia, the ACL averages a length of 31 to 38 mm[14,15] with a midsubstance width of 10 to 12 mm.[14,15,22] The middle third of the ligament is its most narrow portion, having an irregularly circular cross-sectional area of 35 mm^2; this is unaffected by knee flexion angle.[23] The fanning out of the ligament begins 10 to 12 mm from either insertion[14] and results in a tripling of cross-sectional area at the ligament insertion sites.[16] Over most of its length, its AM bundle courses anterior to the PL in all positions of flexion and extension, which results in tensioning of the AM with flexion, and the PL with extension.[14,19,24] This unique load-sharing pattern helps distinguish the AM and PL bundles of the ACL.[16]

Microanatomy

The ACL is unusual, being intraarticular yet extra-synovial. Deep to the synovial covering lies the paratenon, the thickest and outermost of 3 connective tissue layers that surround the ligament. Beneath this layer lies the endotenon and epitenon, dividing the ligament into subfascicles and fascicles, respectively.[25] Collagen fibers from the ligament predictably interweave through transitional zones of fibrocartilage and mineralized fibrocartilage to achieve ligament insertion into bone.[26] As the fibrocartilage is avascular, the ACL must take most of its blood supply from surrounding synovial soft tissue and little from adjacent bone. The overlying synovial fold is rich in vessels, receiving branches from the middle geniculate artery and occasional contributions from the lateral inferior geniculate artery to form a vascular plexus. Similarly, branches of the tibial nerve innervate the ACL via the synovial fold.[27] Nerve fibers accompany the vascular plexus and send axons to penetrate the ligament. Studies have found Golgi-like tension receptors near the ligament ends[28] and apparent Golgi tendon organs along the ligament surface.[29] Within the deep substance of the ACL, there are a few mechanoreceptors accounting for the ACL's afferent role in knee proprioception.[17,29,30] Most mechanoreceptors are localized to the tibial half of the ligament and consist of slow-adapting Ruffini types, which perceive position within limits of motion, and rapidly-adapting Pacinian corpuscles, which sense motion in