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General Review

A Review on Biomechanical and Treatment Aspects Associated with Anterior Cruciate Ligament

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Abstract

Anterior cruciate ligament (ACL), a structure involved in providing knee stability, is an important restraint for anterior tibial translation and secondary restraint for internal tibial rotation. Injury to ACL, leading to its rupture can cause a lot of problems such as effect on knee stability, cartilage wear and other joint structures. Understanding the anatomy, physiology and the mechanical behavior is important as it helps in the understanding of its function and healing capacity after injury. This review takes a brief look at the anatomy, physiology and mechanical behavior of ACL. The causes of injury and healing process of ACL have also been discussed. This review gives an overview of the surgical treatment options for ACL rupture. These treatment options include methods that have been abandoned like primary repair, methods that are currently in use like the biological grafts and prosthetic grafts that are no longer being used (except LARS which is currently not used widely) due to the complications associated with them. Non-surgical, conservative treatment options for ACL have also been discussed.

Keywords: Anterior cruciate ligament; Biological graft; Allograft; Autograft; Synthetic ligament; ACL reconstruction

1. Introduction

Anterior cruciate ligament (ACL) is an important structure of the knee that provides stability to the joint. There are 250,000 new ACL ruptures each year, more than 100,000 ACL reconstructions are procedures are done in the US annually [1]. Apart from the different surgical options, primary repair is an alternative for ACL rupture but is not used without augmentation due to poor outcome [2–4]. Biological grafts like allograft and autograft are being used for ACL reconstruction. Bone patellar tendon bone (BPTB) autograft is the gold standard for ACL reconstruction and produces good outcome [1]. Donor site morbidity is one of the complications associated with autografts. The complications associated with autografts can be avoided by using allogenic grafts [1,5]. Allograft come with their own set of complications like disease transmission and incorporation of graft tissue [5]. All the complications associated with biological grafts (allograft and autografts) can be avoided by using synthetic grafts/ligaments, but the complications associated with these synthetic devices led scientists to abandon them over 2 decades ago [6]. Ligament Augmentation and Reconstruction System (LARS) is a synthetic ligament. Currently it is not being used widely.

This review paper covers the anatomy and physiology of ACL. Causes of ACL rupture have been mentioned in this review along with a brief coverage of the treatment options for ACL.

2. Natural anterior cruciate ligament (ACL)

2.1. Anatomy

The anterior cruciate ligament is attached to the femur at the medial surface of its lateral condyle. The fossa by which it

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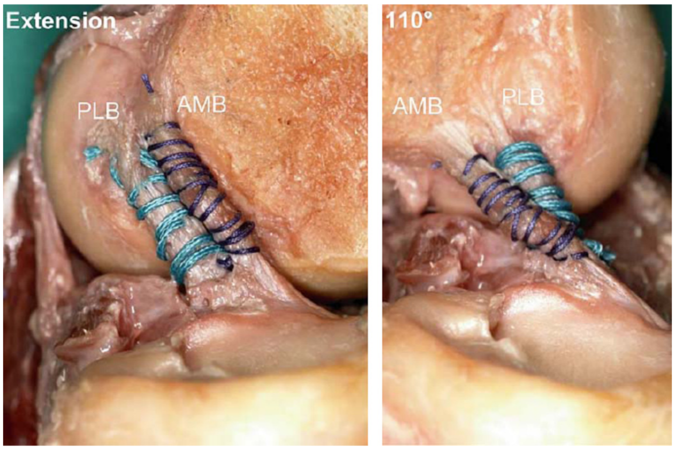

Fig. 1. The figure shows both AM and PL bundles. During knee flexion, the AM bundle tightens, and the PL bundle slackens. At 110° of flexion, the two bundles cease to remain parallel; the AM bundle moves in spiral fashion around the ligament [73].

attaches to the femur is located posteriorly. The anterior cruciate ligament moves anteriorly, medially and distally as it moves through the joint, the fossa tibia that is the attachment site for ACL is located in front and lateral to the anterior of the tibial spine [7]. The width of ACL varies; the ligament fans out as it approaches its tibial attachment site. The narrowest diameter is found at the midsubstance. The insertions site of ACL are larger compared to the midsubstance of the ligament [8]. The ligament seems to turn itself in a spiral as it courses through the knee joint, the rotations is approximately 90° [7,8]. The length of ACL varies from 22–41 mm and the width varies from 7–12 mm [8,9]. Fibers of ACL may blend with the lateral meniscus [7,9]. The tibial attachment of ACL is stronger and wider as compared to the femoral attachment [10].

ACL is not a single band of connective tissue but is divided into functional bundles. ACL is divided into two bundles, anteromedial (AM) and posterolateral (PL) bundle [8,9]. The bundles are named according to the site of tibial insertion. The AM bundle originates from the proximal part of femoral attachment site and is inserted into the anteromedial portion of the tibial attachment site. The fibers of the PL bundle originate from the distal site of femoral origin and are attached to the posterolateral site of tibal attachment site. During extension, PL is tight and AM is moderately lax, this is reversed when the knee is flexed [9,11]. During full extension there is a variation in length of the two bundles [9]. (See Fig. 1.)

The ACL is surrounded by a fold of synovium, so it is extrasynovial. There are three sources of blood supply to ACL the middle genicular artery, medial and lateral inferior genicular artery [8,12,13]. Vascular soft tissue is involved in ACL repair [7,9,12,13]. The blood supply to ACL is not homogeneous; the proximal part of the ligament having a richer supply of blood vessels as compared to the distal part [9]. Avascular areas have been found near the attachment site of ACL, consequently causing the poor healing of ACL [8,9]. The receptors present in ACL are the Ruffini (stretch) and nociceptors (free nerve ending). The mechanoreceptors are responsible for the accuracy of joint position. The nerve supply of ACL is responsible for proprioception [8,9].

2.2. Physiology

ACL is a primary restraint for anterior tibial translation and a secondary restraint for internal tibial rotation [11]. In a study conducted by Girgis et al., when the ACL was cut, the knee could be hyperextended with a 25° increase in extension. There was an increase in internal and external rotation of the tibia and flexed and extended position of the knee [10]. The tension of the fibers of the functional bands of ACL varies with different angle of motion. Zantop et al. showed that under anterior tibial load, anterior tibial translation (ATT) was increased in AM bundle deficient knee for high angel of flexion (60° and 90°) and at low angle (30°) for a PL deficient knee. While for a combined rotator load, ATT increased significantly at from 0° to 30° (of knee flexion) for a PL deficient knee. While AM played an important role for ATT restraints under anterior tibial load, its role for combined rotational load was not significant. PL bundle plays an important role in combined rotator load [11].

2.3. Mechanical behavior of anterior cruciate ligament

The biomechanical property of ACL is determined by the shape and the tensile properties of the midsubstance and the bone insertion points of the ligament. The biomechanical properties are determined by applying load and measuring the corresponding elongation of the ligament. The load elongation curve shows that applying load on the ligament increases ligament stiffness, consequently resisting excessive joint motion on high external load [14].

The different length of fibers in the bundles prevent the uniform loading of the ligament, due to which the femur–ACL–tibia complex is mechanically tested in two orientations: anatomical and tibial. The stiffness, ultimate load and energy absorbed at failure was high for anatomical orientation as compared to the tibial orientation [15]. According to a study conducted by Butler et al. the moduli for the ligaments (LCL, ACL and PCL) was ranged from 278–447 MPa and the maximum stress varied from 30–44 MPa [16].

3. Injury

The injuries to ligaments are characterized into 3 types, depending on the severity of the damage. First category of injuries may encompass micro-failure of the collagen fibers and some pain. There is no joint instability. Injuries categorized in the second category involve partial ligament rupture, with pain and some joint instability. There is a 50% decrease in strength and stiffness of the ligament. The third category involves complete instability of the joint. In this case most of the collagen fibers are ruptured. Applying load on an unstable joint produces abnormal stresses on the articular cartilage which causes early osteoarthritis in humans [17].

The ACL injuries can be categorized into two types (depending on how they are sustained): contact and non-contact