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MISE AU POINT

ACL injury and reconstruction: Clinical related in vivo biomechanics☆

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Summary Several researchers including our group have shown that knee joint biomechanics are impaired after anterior cruciate ligament (ACL) injury, in terms of kinematics and neuromuscular control. Current ACL reconstruction techniques do not seem to fully restore these adaptations. Our research has demonstrated that after ACL reconstruction, excessive tibial rotation is still present in high-demanding activities that involve both anterior and rotational loading of the knee. These findings seem to persist regardless of the autograft selection for the ACL reconstruction. Our results also suggest an impairment of neuromuscular control after ACL reconstruction, although muscle strength may have been reinstated. These abnormal biomechanical patterns may lead to loading of cartilage areas, which are not commonly loaded in the healthy knee and longitudinally can lead to osteoarthritis. Muscle imbalance can also influence patients' optimal sports performance exposing them to increased possibility of knee re-injury. In this review, our recommendations point towards further experimental work with in vivo and in vitro studies, in order to assist in the development of new surgical procedures that could possibly replicate more closely the natural ACL anatomy and prevent future knee pathology.

Introduction

The anterior cruciate ligament (ACL) is composed of two functional bundles, the anteromedial (AM) and the posterolateral (PL) named by their tibial attachment [1—4]. Tension in the AM bundle increases with knee flexion, whereas the PL bundle takes up greater tension in extension and in response to coupled internal rotation [5,6]. The ACL is the guide of the screw-home mechanism. This refers to an ''automatic'' type of axial rotation that is inevitably and involuntarily linked to movements of flexion and extension. When the knee is flexed, the tibia is internally rotated. As the knee is extended, the femoral condyles roll and glide on the tibial condyles, the tibia is gradually externally rotated and at full extension the knee joint ''locks'' presenting the maximal stability at the upright standing position. This

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screw-home mechanism is very important for the synchronization of the knee joint to the adjacent joints of the hip and the ankle. Although the principal movement of the knee is flexion-extension, the internal-external rotation plays a very significant role especially in all these activities that include pivoting.

In the clinical setting, the anterior tibial translation is estimated with the Lachman-Noulis test, a reliable noninvasive diagnostic test for the ACL rupture. As Paessler H. and Michel D. reported [7], this test was originally described by George K. Noulis (1849—1919) in his doctoral thesis ''Entorse du genou'' which was defended at the University of Paris in 1875 [8]. This was perhaps the first biomechanical study on knee ligaments in cadavers.

Aristotle (384—322 BC) stated the principal idea that ''every movement requires a cause''. This is the main core of interest of the in vivo biomechanics. The movement is studied with the kinematics and the cause is studied with the kinetics. Through its long history, in vivo biomechanics can nowadays be a valuable tool also for the arthroscopic surgeon. In recent years, important findings with clinical relevance have arisen from in vivo biomechanical studies and have improved our understanding for the ACL deficient and the ACL reconstructed knee and more interestingly has influenced even the way that we operate these patients. The current review article presents significant amount of knowledge regarding the in vivo biomechanics of an ACL-deficient patient, starting from the ACL rupture, including the ACL reconstruction and being completed with the return to sports and previous activity level.

ACL injury risk factors and prevention

In team sport settings, 50 to 80% of ACL injuries occur in non-contact situations [9—11]. The risk factors for a non-contact ACL injury can be divided into four categories: environmental, anatomical, hormonal and biomechanical—neuromuscular [12]. From a biomechanical perspective, ACL is loaded not only by extreme anterior translation, but also by both valgus and internal rotation moments. In fact, during landing and sidestep cutting tasks, anterior drawer load in isolation is probably not sufficient to injure the ACL and rather a loading combination on the three movement planes is needed to increase the likelihood of rupture. Besides that, when the knee flexion angle increases, there is a reduction in the resultant strain on the ACL [13—17].

The following biomechanical factors are not directly connected with the actual knee movement patterns, but also seem to play an important role on increasing the injury risk: decreased core stabilization and balance, low trunk and hip flexion angles and high ankle dorsiflexion when performing sport tasks. Furthermore, the combination of lateral trunk displacement with increased knee abduction moments and increased hip internal rotation with tibial external rotation exposes the ACL in high risk [13].

Neuromuscular deficiencies are also commonly observed in female athletes and have been classified in three categories: The 'ligament dominance' appears when an athlete absorb a significant portion of the ground reaction force during sports maneuvers with the knee ligaments, rather than the lower extremity musculature [18]. 'Quadriceps dominance' is the preferential activation of the knee extensors over the knee flexors during high-torque force movements [19]. 'Leg dominance' is the side-to-side imbalance on strength and coordination between the dominant and the other leg, which may increase the risk for both limbs [19—21].

The prevention programs have focused on neuromuscular training methods to change the above-described modifiable biomechanical and neuromuscular risk factors and to reduce the non-contact ACL injury rates [22]. Most of these effective prevention studies included a combination of proprioceptive, neuromuscular and core balance training, plyometric, closed kinetic chain and other strengthening exercises, in order to modify the sport-specific movement patterns that lead to increased ACL injury risk.

More specific, the intervention programs focus on normalizing the landing technique [23], decreasing the valgus and internal/external rotation moments on cutting maneuvers [23] and increasing the hamstrings [19,24] and gluteal [25] muscles recruitment and strength.

Rupture pattern and injury mechanism of the ACL

ACL injury is very common during athletic performance compared to the incidence in the general population [26]. Recently, the interest on ACL failure has been increased since several studies highlight ACL injury as a risk factor for knee osteoarthritis regardless of ACL reconstruction [27,28]. During ACL injury, the most common symptoms include pain, audible pop, and oedema. The presence and importance of these signs in relation to isolated ACL injury have been evaluated in the past [29]. Several studies have contributed in better understanding of the biomechanical properties of the ACL like strength [30], stiffness [31] and tension patterns in relation to its failure properties [32].

A very interesting point is that a part of ACL fibers fail initially while the rest remain intact and have the ability to withstand load [32]. This condition could represent the partial ACL tear or the tear of only the AM or the PL bundle of the ACL. Three different patterns have been described in both in vitro and in vivo studies. All of these agree that the final pattern is related to the biomechanical features of the ACL and the mechanism of the injury [33,34].

Acute ACL rupture is accompanied in more than 80% by bone bruises, shown in MRI scanning. Spindler et al. [35] showed that 86% and 67% of the contusions involved the lateral femoral condyle (LFC) and lateral tibial plateau (LTP) respectively; in 56% of the cases, bruises at both sides occurred. Lesions in the medial femoral condyle (MFC) and medial tibia plateau (MTP) were less common (7% and 21% respectively). During the ACL injury, the tibia subluxes anteriorly and rotates internally subjecting the anterior parts of femoral condyles and posterior parts of tibial plateaus to direct contact. The excessive internal rotation of the tibia explains why the contusions of the LFC are usually more anterior than those seen on the MFC [36]. The axial and valgus force applied on the knee especially during contact injuries also plays an important role.