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Suture augmentation following ACL injury to restore the function of the ACL, MCL, and medial meniscus in the goat stifle joint

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ABSTRACT

Functional tissue engineering (FTE) approaches have shown promise in healing an injured anterior cruciate ligament (ACL) of the knee. Nevertheless, additional mechanical augmentation is needed to maintain joint stability and appropriate loading of the joint while the ACL heals. The objective of this study was to quantitatively evaluate how mechanical augmentation using sutures restores the joint kinematics as well as the distribution of loading among the ACL, medial collateral ligament, and medial meniscus (MM) in response to externally applied loads. Eight goat stifle joints were tested on a robotic/universal force–moment sensor testing system under two loading conditions: (1) a 67 N anterior tibial load (ATL) and (2) a 67 N ATL with 100 N axial compression. For each joint, four experimental conditions were tested at 30°, 60°, and 90° of flexion: the (1) intact and (2) ACL-deficient joint, as well as following (3) suture repair of the transected ACL, and (4) augmentation using sutures passed from the femur to the tibia. Under the 67 N ATL, suture augmentation could restore the anterior tibial translation (ATT) to within 3 mm of the intact joint ($p > 0.05$), representing a 54–76% improvement over suture repair ($p < 0.05$). With the additional axial compression, the ATT and in-situ forces of the sutures following suture augmentation remained 2–3 times closer to normal ($p < 0.05$). Also, the in-situ forces in the MM were 58–73% lower ($p < 0.05$). Thus, suture augmentation may be helpful in combination with FTE approaches for ACL healing by providing the needed initial joint stability while lowering the loads on the MM.

1. Introduction

With advances in functional tissue engineering and regenerative medicine, there has been a renewed clinical interest in stimulating healing of a torn anterior cruciate ligament (ACL) of the knee through biological augmentation (Gobbi et al., 2009; Steadman et al., 2006). Large animal studies have also demonstrated that adding growth factors, cells, and scaffolds could accelerate its healing response (Agung et al., 2006; Joshi et al., 2009; Rodkey et al., 2006; Wiig et al., 1990). However, the healing process of the ACL is slow. As such, mechanical augmentation may be required for initial joint stability since the ACL is an essential stabilizer (Murray et al., 2010; Seitz et al., 2008). It should be noted that the concept of mechanical augmentation of an injured ACL has existed for decades. Although, complications in some clinical studies, including chronic inflammation, fatigue failure, and debris in the joint space, led to concerns about placing a large synthetic graft in the knee joint (see Kumar and Maffulli (1999) for a thorough review of this topic).

However, when used in combination with biological augmentation to accelerate the natural healing response, these mechanical augmentation procedures are not meant to be a permanent replacement of the ACL and can be done with a small amount of suture material, which is routinely used in surgical procedures (e.g. for rotator cuff repair). For example, Fleming et al. (2008) have shown that suture augmentation, in which sutures are passed from bone to bone, could indeed better restore anterior joint laxity compared to suture repair under an anterior tibial load in the porcine model.

Nevertheless, the impact of suture augmentation on the other soft tissues, such as the medial collateral ligament (MCL) and medial meniscus (MM), is not known. Even small changes in joint kinematics may lead to substantial alterations in their loading. In our research center, we have shown that transecting the ACL led to large increases in the in-situ forces within both the MCL and MM (Allen et al., 2000; Ma et al., 2000; Papageorgiou et al., 2001a, 2001b; Sakane et al., 1999). Similarly, in-vivo goat studies following ACL transection found degenerative changes in the MM as early as 8 months (Jackson et al., 1999).

Thus, the current research question was whether suture augmentation following ACL transection could restore joint function, including the contribution of the MCL and MM. The objective

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