INTRODUCTION: Meniscal tears are a common cause of knee pain and disability. However, partial meniscectomy, the mainstay of surgical treatment, can lead to long-term joint degeneration [1]. We have developed a novel poly(e-caprolactone) nanofibrous scaffold which can be used to produce cell-laden constructs with meniscus-like properties, and ordered cellular and matrix deposition in vitro [2]. The scaffolds can be formed into geometries that match the anatomic wedge shape of the natural meniscus [3]. We also developed a large animal model (ovine) of partial meniscectomy to study scaffold performance in an in vivo load bearing environment [4]. However, the ability of the scaffold to carry knee joint loads immediately after implantation and how its function compares to an unfilled partial meniscus defect is unclear. The objective of this study was to assess the functional performance, i.e. the ability to carry and distribute knee joint loads, of our nanofibrous scaffold. We mimicked the forces across the ovine knee joint using a customized simulator [5], and used a measure of joint contact pressure distribution on the tibial plateau to test the hypotheses that (a) our surgical approach would not significantly alter the tibial contact pressure compared to intact controls, (b) partial meniscectomy would increase contact pressures and decrease contact areas, (c) placement of the nanofibrous implant into the meniscal defect would result in stiffer mechanics that more closely matched controls, and (d) total meniscectomy would result in higher contact pressures and lower contact areas than partial meniscectomy.

METHODS: Three ovine cadaveric knees were stripped of all soft tissues except for the collateral and cruciate ligaments and menisci. A pin was placed through the epicondylar axis, and each specimen was mounted on the test frame of a force-controlled knee joint simulator that was programmed to apply physiological, multidirectional, dynamic loads which corresponded to ovine gait across the knee [5]. A pressure sensor was mounted over the medial tibial plateau (4010N, Tekscan Inc., MA). The knee was tested under 5 conditions: intact, femoral osteotomy, partial meniscectomy, scaffold repair, and total meniscectomy. A medial femoral osteotomy was performed in order to surgically access the posterior horn of the medial meniscus to match the surgical approach used in the in vivo model [2]. In all conditions, the osteotomy was reduced and stabilized with the same lag screw. In the partial meniscectomy group, a 6mm x 6mm box defect was made in the posterior third of the medial meniscus [2]. The nanofibrous scaffold was implanted into the partial meniscus defect using 4 modified vertical mattress sutures [2] (Figure 1). For each joint and condition, 10 cycles of simulated normal ovine gait were applied through the test frame, and pressure transmission was simultaneously recorded through the tibial plateau. The pressure distribution on the tibial plateau was visually assessed for each condition and the movement of the center of the force used to understand the arc of movement of the femur across the tibial plateau. Peak contact pressures and total contact area were computed at the time point during the gait cycle in which the axial force reached a maximum (17% of gait). These outcomes were computed for each condition, from each of the three joints assayed. One-way ANOVA with Fisher’s LSD post hoc tests were used to establish statistical significance with p<0.05.

RESULTS: The distribution of contact pressures across the tibial plateau was sensitive to meniscal manipulation (Figure 2). The center of force arc, reflecting the normal femoral rollback mechanism, was dysfunctional following partial meniscectomy, but was restored following scaffold repair (Figure 2). There was no significant difference in contact pressure or area between the intact and osteotomy conditions, suggesting that the reduction of the osteotomy returns the joint to normal patterns of load transmission. Following partial meniscectomy, contact pressures increased 43% (p=0.001) and contact areas decreased 48% relative to controls (p=0.004) (Figure 3). With placement of the nanofibrous scaffold (scaffold repair group), an 18% reduction in contact pressure was observed compared to the partial meniscectomy group (p=0.028). Subsequent removal of the entire meniscus (total meniscectomy group) returned contact pressures to that of the partial meniscectomy group, and further reduced contact area.

DISCUSSION: Tissue engineered constructs for meniscus repair and/or replacement are a promising solution for an insolvable and common orthopaedic condition. Prior to human clinical trials, efficacy of these engineered materials must be demonstrated in a large animal model. Towards that end, we developed an ovine model of meniscus repair, and show here that our surgical approach to the posterior horn of the medial meniscus does not significantly alter joint contact pressures or area. Moreover, while partial meniscectomy significantly increased contact pressures and decreased contact areas relative to controls, repair with our nanofibrous constructs decreased contact pressures relative to partial meniscectomy. Additionally, scaffold repair appeared to restore normal kinematics during femoral rollback. These data suggest that this technology holds promise for the development of functionally competent meniscal implants, and support our transition towards longer term in vivo studies to evaluate preservation of cartilage and joint health.

Figure 1: Surgical approach showing femoral osteotomy and defect creation (A), nanofibrous implant formation and placement (B, inset), and the implant in situ prior to osteotomy reduction (C).

Figure 2: Pressure maps of a knee at 17% of gait cycle under each of the experimental conditions (top). Center of force trajectory for each condition through the gait cycle (bottom, white tracing).

Figure 3: Contact pressure (left) and area (right) computed for each condition at 17% of the gait cycle. Bars: p<0.05, n=3 per condition.


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