Biomechanical Consequences of Surgical Destabilization of the Medial Meniscus in the Rabbit Knee

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Purposes: In post-traumatic OA, cumulative abnormal contact stress presumably plays an important role in the disease progression in the chronic phase. To study details of the disease mechanisms, or to pilot treatment(s) to alter the disease process, a survival animal model in which OA predictably develops purely due to cumulative abnormal contact stress is crucial. For this purpose, a new surgical insult technique to model localized contact stress elevation in the rabbit knee has been developed. In this technique, the posterior root of the medial meniscus is surgically destabilized through a posterior arthrotomy. Our earlier pilot work has suggested that living rabbit knees after medial meniscus destabilization (MMD) relatively frequently exhibit distinct cartilage degeneration in the medial compartment (Mankin score ≥ 4 points) in 8 weeks, with the severity comparable with those after total medial meniscectomy or ACL transection [1]. It is theoretically expected that MMD causes dramatic elevation of contact stresses in the medial compartment, while preserving whole-joint stability near intact. The goal of this study was to determine the immediate effects of MMD on the rabbit knee joint mechanics, particularly contact stress distribution in the medial compartment and sagittal-plane laxity.

Methods: A total of sixteen New Zealand White rabbit cadaver knees (from different animals) were utilized. These specimens were dissected free from soft tissue, with all major knee ligaments preserved uninjured. Half of these specimens (n = 8) were subjected to an axial compression test to measure contact stress distribution in the medial compartment. The whole-joint construct, with its distal femur and proximal tibia potted into separate PMMA blocks, was mounted in an MTS-based custom loading device (Figure 1A) with the knee in approximately 135 degrees flexion (habitual physiological flexion angle). Adduction/abduction was unrestricted. A physiologic axial compression force of 80 N was then applied, and contact stress in the medial compartment was measured using pressure-sensitive film (Prescale®, Fujifilm Co., Tokyo, Japan) inserted into the knee above the meniscus. To measure changes in the contact location, the position of the film with respect to the femur was registered using two K-wires inserted anteriorly and posteriorly to the medial femoral condyle (Figure 1B, C). Each specimen was initially tested with the menisci left intact (Baseline). Then, the test was repeated after sharply transecting the posterior root of the medial meniscus (MMD) and after removing the whole medial meniscus (TMM). The data were analyzed to extract the peak contact pressure, contact area, and the contact location (coronal and sagittal position of the center of contact patch, Figure 1B, C), using a custom MATLAB program. In the other half of specimens (n = 8), sagittal-plane joint laxity was measured in terms of neutral-zone length (NZL), using a technique previously described elsewhere [2]. Each specimen was again tested in the above-noted three conditions (Baseline, MMD, and TMM). For all statistical tests, significance was taken as p < 0.05.

Results: In Baseline, the medial compartment contact area was 12.1 ± 2.6 mm², and the peak contact stress was 4.6 ± 0.7 MPa (Figure 2). Contact area results in both MMD (7.1 ± 1.6 mm²) and TMM (7.2 ± 1.5 mm²) were significantly lower than in Baseline (p < 0.001, for both). The mean decrease was -41% and -40%, respectively. Peak contact stress results in both MMD (7.1 ± 0.4 MPa) and TMM (7.2 ± 0.4 MPa) were significantly higher than in Baseline (p < 0.001, for both). The mean increase was +54% and +57%, respectively. In MMD, the center of contact patch significantly shifted laterally (0.4 ± 0.2 mm, p = 0.001) and anteriorly (0.3 ± 0.4 mm, p = 0.04) from Baseline. Similarly significant shifts, 0.3 ± 0.2 laterally (p = 0.01) and 0.3 ± 0.3 mm anteriorly (p = 0.02), were identified in TMM. In the joint laxity test, mean NZL values in Baseline, MMD, and in TMM were 0.99 ± 0.23 mm, 1.04 ± 0.23 mm, and 1.07 ± 0.17 mm, respectively. Statistically significant changes associated with MMD and TMM were not evident (p-values: 0.45 and 0.26, respectively).

Discussion: The contact stress data suggest that MMD dramatically changes articular contact mechanics in the rabbit knee medial compartment, with the effect comparable to TMM. Given that MMD predictably causes PTOA in mouse knees [3], this surgical insult technique works similarly in the rabbit knee. The laxity data suggests that the effect of MMD on whole-joint stability is relatively small, implying that overall joint function could be preserved. The present MMD technique appears to be an effective surgical insult modality to model cumulative abnormal contact stress in living rabbit knees.

Significance: A survival rabbit model using this insult technique will facilitate translational research to improve orthopaedic treatment for post-traumatic OA.


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