INNER STRAIN OF THE MENISCUS UNDER JOINT LOAD

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Introduction:

The meniscus has been reported as an important structure for knee kinematics and prevention of the degenerative joint disease. The load transmission is one of the important functions of the meniscus. Nevertheless, neither modes nor magnitudes of the meniscal deformation under joint load have yet been fully investigated. The inner strain of the meniscus under joint load could not be measured directly but simulated with the finite element model. Assuming that the interactions between the meniscal and articular cartilage are frictionless, loads transmitted to the meniscus must be perpendicular to the meniscal surface. On the femoral surface, the load will be both an axial and a radial vector. The radial vector extrudes the meniscus radially, and the axial vector causes the compressive deformation in the meniscus.

In the present study, we measured the magnitude of both radial extrusion and compressive inner strain of the meniscal body under joint load. The characteristics in the deformation of the meniscus were assessed by comparing radial extrusion and compressive strain among different anatomical locations.

Materials and Methods:

Seven fresh-frozen porcine stifles were dissected of soft tissue, patella and anterior joint capsule. Both lateral and medial collateral ligaments (LCL and MCL) were detached at the femoral insertion sites with bone fragments, and then lateral meniscus was exposed. Thin stainless steel wire with 100 µm in diameter was inserted through an injection needle. Four horizontal and three vertical wires were inserted in the coronal plane at the middle portion of the meniscus (Fig.1). Finally, LCL and MCL were repaired with bone fragments reattached using bone screws.

The stepwise joint loads were applied using a specially designed experimental rig from 50 N to 800 N, and radiographs were taken in the antero-posterior direction under each joint load. Radiographs were digitized using an image scanner with 12 µm of resolution. The intersections of the thin wires served as the inner markers of the meniscus. We digitized the position of each marker in the two dimensional coordinate system on the tibia using NIH image analysis software. Three markers of each four horizontal wires were designated as red-red (RR), red-white (RW) and white-white (WW) zone markers from periphery to the center of the meniscus respectively. Four markers of each zone were named as femoral (F), mid-femoral (MF), mid-tibial (MT) and tibial (T) portion markers from femoral to tibial side. The position of each marker under 50 N load served as reference point. The radial extrusion (mm) of each marker and the compressive strain (%) among four markers at each zone were calculated. Regional variation in each parameter was evaluated using repeated measures ANOVA among 3 zones and 4 portions. The level of significance was p<0.05.

Results:

All markers were extruded radially with the increase of joint load. The magnitudes of radial extrusion at RR zone were significantly less than that in other zones. With the comparison among portions, the femoral portion had significantly less radial extrusion than the other portions (Fig.2). The marker in F portion at RR zone was found to have least radial extrusion under joint load.

The compressive strains between F and T portion had statistically significant differences among three zones (Fig.3). At the WW zone, the compressive strain increased with joint loading. On the other hand, the compressive strain decreased gradually at the RR zone, where the height of meniscus increased with the increase of joint load. Furthermore, at the RW zone, the joint load did not affect the compressive strain.

Discussion:

Assuming the displacement of wire in the meniscus would be minimal in the transverse direction, we employed the intersection of thin wire as the inner X-ray marker of the meniscus, and analyzed the deformation inside meniscus using radiographic image analyses. Our data demonstrated the regional differences in the mode and the magnitude of deformation inside the meniscus. We found the RR zone and F portion of the meniscus was more stable against the radial vector of joint load, and the RR zone increased in height even under joint loading. These modes of deformation of meniscus might be beneficial to keep the joint congruity and optimize the load transmission. The possible reasons for these characteristics of the inner strain of the meniscus would be the regional variations in the mechanical properties, especially in the modulus under circumferential tensile stress (hoop stress) caused by joint loading.

References: