THE ACUTE EFFECT ON IMPACT ON THE MECHANICAL PROPERTIES OF ARTICULAR CARTILAGE

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Introduction: Although many investigators have studied the effect of impact loading of articular cartilage in terms of chondrocyte viability, little is known about attendant changes in the viscoelastic properties of the extracellular matrix. However, to a large extent, the properties of the matrix determine the mechanical environment of chondrocytes during loading. We hypothesize that impact loading may alter the intrinsic properties of articular cartilage, increasing chondrocyte stresses and initiating inflammatory changes within the joint. In this study we investigate the effects of impact loading on the mechanical and viscoelastic properties of articular cartilage.

Methods: Twenty-four bovine knee joints were frozen within 24 hours of sacrifice. The lateral condyle was excised and allowed to thaw for 1 hr in solution containing 0.15 M NaCl, DPBS, 2 mM EDTA, 5 mM benzamidine HCl, 10 mM N-ethylmaleimide, and 1 mM PMSF. A test site was selected on the central portion of each lateral condyle and marked with India ink. The viscoelastic properties of the cartilage were measured with an automated indentation apparatus with a porous indenter (diam: 2 mm). Initially, a tare load of 0.0098 N was applied for 15 minutes, followed by application of a test load of 0.049 N. The specimen was then allowed to creep until the rate of displacement of the indenter was less than 1x10^{-6} mm/sec. The load was then removed and the recovery of the indented surface was monitored. Once the recovery phase was complete, the thickness of the cartilage at the site being measured was determined using a penetrating steel needle probe. The indentation data were modelled using the biphasic creep and stress relaxation theory of Mow et al. (1980) combined with the numerical algorithm ("master curve") proposed by Mow et al (1989). This methodology yielded values of the aggregate modulus, Poisson’s ratio, and the permeability of articular cartilage at each test site.

Once the indentation test was completed, each osteochondral specimen was immersed in media for 15 minutes, mounted in a drop tower, and impacted. This apparatus created a zone of uniform compressive stress of approximately 13mm2 located over the indentation measurement site. By varying the height of the drop weight, peak stresses of 10, 15, or 20 MPa were generated at impact, as measured by a piezoelectric force transducer mounted on the impactor (Figure 1). Once the impact occurred, the osteochondral specimen was stained with India ink documenting any articular damage, and placed into media. After equilibration for 2 hours, the biphasic indentation test was repeated at the site of injury. The statistical significance of differences in each viscoelastic parameters measured before and after impact were calculated with an ANOVA and the Students’ t-test.

Results
There was no significant change in any of the properties of the cartilage explants after impact loading to 10MPa. However, after exposure to 15MPa and 20MPa, the permeability of the articular cartilage rose by 34% (p<0.05) and 88% (p<0.05) respectively. The Aggregate Modulus (MPa) decreased significantly (p<0.05) after both the 15 MPa (-24%) and 20 MPa (-23%) stress injuries. Similarly, the reduction in shear modulus (MPa) after impact was statistically different (p<0.05) compared to pre-impact values at both the 15 and 20 MPa.

Discussion: Impact loading of articular cartilage to peak compressive stresses in excess of 10MPa causes significant damage to the extracellular matrix. Exposure to single impacts of 15 and 20 Mpa causes cartilage to become softer and more permeable with reduced ability to resist shear forces. Based upon the data presented, the initial integrity of the articular cartilage after acute injury may be an important factor in preventing degenerative changes. This suggests that once the articular surface sustains an impact injury, the threshold stress level for additional injury may be reduced, increased risk of secondary pathology. Further investigation is needed to study the effects of repetitive loading, cartilage repair, and the response of chondrocytes exposed to these transient loads.

References