VISCOELASTIC BEHAVIOR OF ARTICULAR CARTILAGE UNDER DYNAMIC SHEAR AND COMPRESSIONAL LOADING FOLLOWING ENZYMATIC TREATMENT

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INTRODUCTION: The viscoelastic behavior of articular cartilage is derived from complex interactions involving the fluid and the extracellular matrix (ECM) of proteoglycans (PG) and collagen fibrils. Enzymatic digestion of the ECM components makes it possible to study specific structure-function relationships of articular cartilage. To some extent, enzymatic treatment also simulates the pathological process found in cartilage matrix during osteoarthritis (OA) progression. In order to understand the role of the ECM component of articular cartilage, various configurations of compressive and shear behaviors have been investigated following the enzymatic degradation with collagenase, trypsin, and chondroitinase [1-5]. The objective of this study was to quantify the role of the matrix components, especially those of collagen and PG, on the compressive and the shear viscoelastic response of articular cartilage as well as to obtain detailed information on the specificity of the selected enzymes.

METHODS: Thirty cylindrical cartilage plugs, 6 mm in diameter, were harvested from five bovine shoulder joints (1-2 months old) that were obtained from a local abattoir. The specimens were divided into two groups: collagenase type VII (30 U/ml) was used for the degradation of the collagen network, and chondroitinase ABC (0.1 U/ml) was used for the specific digestion of PGs. The specimens were immersed in Minimum Essential Medium with Earle’s salt and antibiotics and incubated under physiological conditions (37°C, CO2 atmosphere) with a specific enzyme. The incubation time was 44 h for both collagenase and chondroitinase. All the specimens were tested before and after treatment; thus each specimen served as its own control. The dynamic viscoelastic properties of the tissue were measured by dynamic compressive and shear loading, with custom-made chambers mounted on the loading devices. During dynamic compressive loading, a 20 % static offset strain was initially applied to each sample; subsequently, a 0.5 % sinusoidal compressive strain was superimposed at frequencies ranging from 0.01 to 0.5 Hz [6]. The dynamic compressive modulus \( E^* \) and loss tangent, \( \tan \delta \), were determined from the measured load-deformation responses. After the dynamic compressive loading, the dynamic shear test was carried out. A 20% static compressive strain was applied before testing to allow a comparison with the compressive response and to produce sufficient friction to enable the transmission of torque to the specimen. After equilibrium was reached, a 0.5 % sinusoidal shear strain was superimposed at frequencies ranging from 0.01 to 0.5Hz [7]. The dynamic shear modulus \( G^* \) and loss tangent, \( \tan \delta \), were determined in a manner similar to that used in dynamic compressive loading.

RESULTS: In the case of the dynamic compressive response, the dynamic compressive modulus \( E^* \) increased along with the loading frequency. At each frequency, a decrease in \( E^* \) was observed after digestion in the case of both collagenase and chondroitinase (Fig. 1A, Fig. 2A). No significant change was observed in the loss tangent in the collagenase-treated group (Fig. 1B); however it significantly increased in the chondroitinase-treated group (Fig. 2B). In the case of the dynamic shear response, the dynamic shear modulus \( G^* \) increased along with the loading frequency. A decrease in \( G^* \) was observed at all frequencies after each of these enzymatic treatments (Fig. 3A, Fig. 4A). Contrary to the compressive response, a significant increase in the loss tangent was observed in the collagenase-treated group (Fig. 3B); however no significant change was observed in the chondroitinase-treated group (Fig. 4B).

DISCUSSION: This study reports the effects of the collagenase and chondroitinase treatments on the dynamic compressive and shear viscoelasticities of articular cartilage. Enzymatic digestion has been previously shown to alter the mechanical properties of articular cartilage. For example, collagenase treatment results in a significant reduction in the dynamic compressive stiffness of articular cartilage while the phase angle was kept statistically constant [5]. Consistent with the results of this previous investigation, collagenase treatment brought about a relative reduction in \( E^* \) as compared with the pre-treated values and also resulted in an insignificant change in the loss tangent. The finding that \( E^* \) and \( G^* \) decreased for both collagenase and chondroitinase treatments confirms the contribution of collagen and PGs to the dynamic stiffness of articular cartilage. The significant increase in the compressive loss tangent, \( \tan \delta_C \), of the chondroitinase-treated samples suggests the significance of PGs for the energy dissipation of articular cartilage under compression. The changes in the loss tangent, \( \tan \delta_C \), of the collagenase-treated samples also suggest the importance of collagen for the energy dissipation under shear loading. These findings may help to elucidate the contribution of the ECM components to the dynamic viscoelastic response of articular cartilage to combine with measurements of collagen and PGs content.

REFERENCES

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