Experimental Determination of Dynamic Mechanical Properties of Normal and Decollagenized Bovine Articular Cartilage Using the Split-Hopkinson Pressure Bar Method

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Introduction. Osteoarthritis (OA) is one of the factors that decrease the quality of life in elderly people. OA causes pain due to the direct contacts with bone to the other bone by the wear of the articular cartilage. The articular cartilage is composed of a liquid layer (about 80% of the wet weight) and a solid layer consisting of a collagen fibers and proteoglycans (about 20% of the wet weight). The collagen fibers have a role in maintaining the structural strength and the shape of articular cartilage (1). The functions of the articular cartilage are to absorb impact load applied to the diarthroidal joints and to reduce friction in bone-to-bone contact by the extremely low coefficient of friction. In diarthroidal joint diseases such as OA, the degeneration of the articular cartilage should cause a decline of such functions. Therefore, this study dealt with the static and dynamic mechanical properties of the articular cartilage through the quasi-static compression and the Split-Hopkinson Pressure Bar (SHPB) experiments. The change in the mechanical properties associated with the degeneration of the collagen fibers was investigated and discussed.

Materials and Methods. The materials used in this study were bovine articular cartilage. The cylindrical cartilage specimens, 8 mm in diameter and 2 mm in length, were machined from bovine tibial proximal plateau. The decollagenized cartilage were also prepared so as to reveal the difference in mechanical response between the normal and degenerated cartilage (n=7 each).

PMMA (polymethyl methacrylate) was used for the input and output bars of the SHPB because of its advantage of low mechanical impedance suitable for high compliant materials. This modification requires to identify the viscoelastic properties of PMMA for the predictions of the time histories of the stress and strain at the both ends of the specimen. To this end, the one-dimensional strain wave propagation in a viscoelastic rod was successfully analyzed based on Fourier analysis (2) in combination with the numerical inverse Laplace transformation.

The quasi-static compression tests were performed at a displacement of 10% of thickness and a loading rate of 1 mm/min while the SHPB experiments were performed at a strain rate of approximately 2000/s (average).

Results. Figure 1 shows typical stress-strain curves obtained by the SHPB tests. The dynamic Young’s modulus was significantly larger than the static Young’s modulus. The both moduluses were significantly lower in the degenerated cartilage than in the normal cartilage (Table 1, p<0.05).

Discussion and conclusion. The dynamic Young’s modulus was significantly larger than the static Young’s modulus. This is probably due to the resistance of liquid phase in the articular cartilage to dynamic load. The degeneration, or loss of collagen fibers resulted in the decrease of the stiffness under both static and dynamic loading conditions.

It concluded that the loss of collagen fibers could cause less resistant to water flows in the cartilage, and eventually led to lower resistant to dynamic load.

![Stress-strain curves](image)

Table 1 Static and dynamic Young’s modulus

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<tr>
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<th>Static modulus [MPa]</th>
<th>Dynamic modulus [MPa]</th>
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<tbody>
<tr>
<td>Normal</td>
<td>2.1 ± 0.3</td>
<td>36.0 ± 3.9</td>
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<tr>
<td>Decollagenized</td>
<td>0.7 ± 0.6</td>
<td>9.9 ± 4.0</td>
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References.