IN SITU COMPRRESSIVE STIFFNESS AND STRUCTURAL INTEGRITY OF HUMAN ARTICULAR CARTILAGE

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Introduction
The biomechanical properties of articular cartilage depend on the content, composition, organization and interaction of its structural matrix molecules. Structural and constitutional alterations may compromise the mechanical competence of this highly specialized tissue. Significant changes in early cartilage degeneration include fibrillation and disorganization of the collagen network (1), a decreased aggregation of proteoglycans coupled with increased tissue hydration (2), leading to softening and a concomitant reduction in cartilage compressive stiffness (3). Animal experiments have shown that macroscopically undetectable alterations in cartilage structure can be revealed as a modification of mechanical properties (4). Softening and reduction of cartilage compressive stiffness may thus be one of the first signs of cartilage degeneration. With the current interest in cartilage repair there is a need to diagnose cartilage disorders at an early stage. Currently, orthopedic surgeons use a classification system for chondropathy, based on visual assessment and palpation of the cartilage surface with a blunt probe (5). The aim of this study was to investigate possible correlations between the structure, the composition and the compressive stiffness of human articular cartilage measured in situ with an indentation device that can be used intraoperatively (6).

Material And Methods
Using a hand-held indentation device (ARTSCAN 1000™), cartilage compressive stiffness was measured on 24 right knees from fresh human cadavers (age: 32-89 years, mean: 65 years). Measurements were performed on the medial (MPG) and the lateral (LPG) facet of the patellar groove and the weight-bearing areas of the medial (MFC) and the lateral (LFC) femoral condyle. Only sites with macroscopically normal or slightly fibrillated surface were assessed. For each location, measurement sites were marked with Indian ink and 3 to 6 indentations per site were recorded. The indenter (Ø 1.0mm) imposed a short (1s), constant (0.3mm) deformation on the cartilage surface. The maximal force by which cartilage resisted this compression was measured. The compressive stiffness of cartilage can be represented by the instant shear modulus derived from the measured force and the geometry of indentation according to an elastic model (7). A Poisson’s ratio of 0.5 and a correction factor for cartilage thickness less than 2mm were used. After biomechanical testing, two osteochondral plugs for biochemical (8) and histological (9) examinations were harvested from each location using a diamond-mounted drill bit. Immediately after harvesting, the cartilage thickness was ascertained with a magnifying lens (magnification: 8x). Specimens for biochemical examination were stored in physiological buffered saline (PBS) at –70° C. Analysis included determination of total proteoglycan content (8) and total collagen content (9).

Samples for histological evaluation were fixed in a 10%-PBS-buffered formaldehyde/1% cetylpyridiniumchloride solution for 2 days, decalcified in 15% EDTA for 2-3 weeks and embedded in paraffin. For each sample, five-micrometer thin sections were stained with Safranin-O/Fast green (SAFG), Masson’s Trichrome, Alcian blue and H-E. With special emphasis to the SAFG slides, the stage of cartilage degradation was assessed according to Mankin’s histological-histochemical grading score (10).

Results
The instant shear modulus varied with location and was higher in the femoral condyles than in the patellar groove (Table 1). There was a significant correlation between instant shear modulus and total proteoglycan or total collagen content (data not shown).

Discussion
Shear moduli for the different locations (Table 1) are comparable to in vivo values for intact knee cartilage of a younger patient population (mean age: 26 years) measured with a similar indentation probe (1). As also observed by other investigators (12, 13), cartilage surface in femoral condyles is stiffer than in the patellar groove.

In the present study we did not see a correlation between cartilage compressive stiffness and the total proteoglycan or total collagen content. There was, however, a significant correlation between the biomechanical properties and the structural integrity of articular cartilage, represented by the histological appearance. This agrees with observations that suggest that in contrast to the equilibrium compressive stiffness, short term compressive stiffness may depend on the integrity of the collagen fibre network and not on the amount of proteoglycans (14).

References
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Table 1: Pooled data for all 24 subjects and each location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Thickness [mm]</th>
<th>Shear modulus [MPa]</th>
<th>Mankin Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>MPG</td>
<td>N=23</td>
<td>2.2</td>
<td>0.11</td>
</tr>
<tr>
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<td>N=23</td>
<td>2.2</td>
<td>0.18</td>
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<td>2.6</td>
<td>0.14</td>
</tr>
<tr>
<td>MFC</td>
<td>N=20</td>
<td>2.2</td>
<td>0.13</td>
</tr>
</tbody>
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Figure 1: Correlation between instant shear modulus (calculated from the measured resistive forces) and histological Mankin score.