Novel Technique to Map the Biomechanical Properties of Entire Articular Surfaces Using Indentation to Identify Early Degenerated (Osteoarthritis-like) Regions

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### Introduction

A currently unsatisfied need in Arthritis and cartilage research is to assess the function of the entire articular cartilage surface both quantitatively and non-destructively. The objective of this study was to investigate the ability of a novel automatic technique to characterize mechanical properties of entire articular surfaces in indentation in order to rapidly discriminate between degenerated versus healthy articular cartilage.

### Methods

1. **Human Distal Femurs (N=8)**
   - Complete articular surfaces from 8 distal femurs were obtained from RTI Surgical, Fl.
   - Articular surfaces were attached to a testing chamber filled with PBS and equipped with a camera-registration system (~1 mm registration resolution) (Biomomentum, Canada). A position grid was superimposed on the image of the sample (Fig. 1).
   - Articular surfaces were visually graded using the ICRS system
     - ICRS 0 (visually normal, outside circled regions in Fig. 6 & 7)
     - ICRS > 0 (visually abnormal, inside circled regions in Fig. 6 & 7)

2. **Ex Vivo Mechanical Assessment of Distal Femurs**
   - A spherical indenter (radius = 3 mm) for this new automated indentation technique (Fig. 2).
   - A multiaxial load cell uses Fx, Fy and Fz to calculate the normal force.
   - A 3-axis mechanical tester (Mach-1, Biomomentum) uses 3 displacement components simultaneously to perform a perpendicular displacement based on the measured surface orientation (Fig. 3).

**Steps performed at each position:**
1. Measure the contact coordinates at a predefined position (Fig. 1)
2. Measure the contact coordinates of 4 surrounding positions
3. Calculate surface orientation using the contact coordinates
4. Perform perpendicular indentation and measure the normal force (Fig. 4)

### Automated Indentation Mapping

- A needle probe replaces the spherical indenter.
- A load cell uses Fz to calculate the force (Fig. 5).
- Thickness measurement with an adapted version of the needle technique
- Mapping of cartilage thickness (vertical distance) over the entire articular surface.
- Cartilage thickness was calculated using the surface orientation previously obtained.

**Instantaneous Modulus**

- The instantaneous modulus at each position was obtained by fitting the load-displacement curve (with corresponding thickness) to an elastic model in indentation

### Automated Thickness Mapping

**Conclusion**

- In contrast to what is usually required for traditional biomechanical testing (i.e. individual sample harvesting, visual orientation of the sample surface perpendicularly to compression axis, sample preservation causing possible mechanical alteration), this technique does not require interventions that are costly and time-consuming, thus reducing considerably sources of measurement error and allowing for high resolution mapping of the entire articular surface.
- This study results clearly demonstrates the capabilities of this novel automatic indentation technique to rapidly, objectively and non-destructively map the biomechanical properties of full articular surfaces and to identify degenerated regions.
- This automatic indentation mapping technique will be of great value in the identification of wear patterns in OA progression and in cartilage repair studies.

### Results

**Thickness Mapping**

![Thickness Mapping](image)

**Instantaneous Modulus Mapping**

![Instantaneous Modulus Mapping](image)

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### References