Development of a Sequence of Mechanical Tests for Articular Cartilage at a Single Location

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Introduction

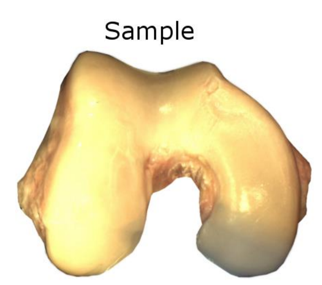
In a recent study, our group has highlighted the importance of considering the natural topographic variability of the mechanical properties of cartilage over the articular surface, particularly in the context of cartilage repair, where one can assess the effect of treatments [1]. Moreover, the availability of test samples is limited in repair studies since the regions of interest are of limited size. A solution to overcome this problematic is to perform multiple tests at a single location over the articular surface. **Therefore, the objective of this study was to develop a sequence of mechanical tests to characterize articular cartilage at a single location**.

SIGNIFICANCE: THE USE OF A SEQUENCE OF TESTS CAN MINIMIZE THE NUMBER OF REQUIRED SAMPLES AND MINIMIZE THE IMPACT OF THE NATURAL VARIATION OF THE MECHANICAL PROPERTIES IN DATA ANALYSIS.

Methods

Tissue Source

- 6 osteochondral cores (D= 3.5 mm)
- Extracted from 5 distal femurs
- Healthy cadaveric human joints
- Provided by RTI Surgical (Florida)



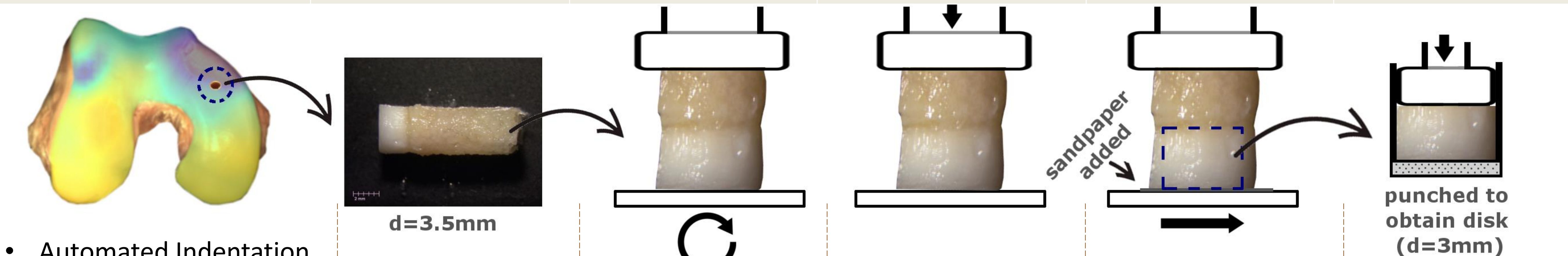
Equipment

- Multiaxial mechanical tester Mach-1v500css (Biomomentum Inc., Canada)
- Camera-Registration system Mapping Toolbox (Biomomentum Inc., Canada)
- Spherical Indenter (D=6.35 mm)
- Flat Indenter (D=12.5 mm)

Sequence of tests

Note: 10 minutes wait was allowed between each test and tests were performed in PBS

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Automated Indentation and Thickness Mapping	Thickness under dissection microscope	Friction	Unconfined Compression	Shear	Confined Compression



Step 1

- Automated Indentation Technique allowed measuring mechanical properties over the entire surface [1]
- The thickness is obtained with an adapted version of the needle technique [1, 2]
- **Instantaneous modulus (*IM*)** extracted by an elastic indentation model [3]
- ***IM* and cartilage thickness (*h*)** of each core was calculated as the average of all values measured within 6 mm from the core center

Step 2

- **Cartilage thickness (*h*)** was re-measured using a dissection microscope

Step 3

- 20% equilibrium strain was applied
- Friction test was executed following a 5 mm circular path (1440° rotation) on glass
- **Coefficient of friction at equilibrium μ_{eq}** was extracted

Step 4

- 10% precompression
- Followed by 5 ramps of 2% stress relaxation
- Data were fit to a poroelastic model with fibril-reinforcement [4] to extract the **matrix modulus (E_m), fibril modulus (E_f) and radial permeability (k_r)**

Step 5

- Sandpaper (1500 grit)
- **Shear modulus (*G*)** at 10%, 15% and 20% compression was extracted

Step 6

- 10% precompression
- Followed by 5 ramps of 2% stress relaxation
- Data were fit to a linear biphasic model [5] where **the aggregate modulus (H_A) and axial permeability (k_z)** were extracted

Results

Sample	Step 1		Step 2	Step 3	Step 4			Step 5	Step 6	
	IM (MPa)	*h* (mm)	*h* (mm)	μ_{eq}	E_m (MPa)	E_f (MPa)	k_r (x10^{-12}m^4/N·s)	*G* (MPa)	H_A (MPa)	k_z (x10^{-12}m^4/N·s)
1	4.7	2.5	2.6	0.32	2.0	21.5	0.0003	0.3	0.5	0.04
2	1.2	2.2	2.3	0.37	0.6	6.2	0.002	0.1	0.6	0.08
3	8.0	2.3	2.2	0.33	3.9	24.6	0.001	0.3	0.8	0.003
4	3.0	2.2	2.5	0.40	1.1	13.5	0.001	0.2	0.5	0.005
5	2.5	2.2	2.5	0.32	1.2	23.1	0.001	0.2	0.5	0.004
6	4.5	1.7	2.1	0.35	1.2	15.5	0.001	0.2	0.7	0.02

- Results present the extracted parameters of the 6 cores from the various test configurations (at 20% strain).
- A significant correlation (r=0.81, p=0.05) was observed between the thickness obtained with the automated thickness mapping (Step 1) and the thickness obtained under the dissection microscope (Step 2).
- The coefficient of friction values are generally higher than stated in the literature, but the reference values found for cartilage on glass in PBS were done on bovine cartilage [6], which might not be comparable.
- E_m is approximately 15 times lower than E_f, which is expected and reported in the literature [7].
- *G* are in the same range than those reported in the literature [8].
- H_A and k_z from confined compression tests are similar to those reported in the literature [9].
- The hydraulic permeability in the axial (confined compression) and radial (unconfined compression) direction have a 10-fold difference for a compression higher than 10% as stated in the literature [10].

Discussion

- The variability between the individual 6 samples in these measurements arises from the spatial distribution pattern since samples are not taken from the same compartment on the articular surface [1].
- The sequence of mechanical tests for articular cartilage at a single location appears to be promising since it provides values consistent with those reported in the literature.
- Additional analyses such as histological or biochemical assessments can be performed after this sequence of mechanical tests on the same sample.
- For future studies, it will be interesting to test cartilage at different states of degeneration to determine which mechanical parameters are more sensitive to degradation and to investigate a correlations between these parameters and additional analyses.

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References:

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