Relevance of the Spatial Distribution of Mechanical Properties of Articular Cartilage in Animal Studies

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Introduction

In order to evaluate the effect of cartilage treatments, appropriate control sites need to be chosen. However, finding the right location for the control site is quite challenging in articular surfaces where a natural spatial distribution of mechanical properties is present in all healthy joints [1]. **The purpose of this study was to assess the importance of considering the spatial distribution of the mechanical properties of normal articular cartilage in animal models of cartilage repair, specifically the distributions of thickness and instantaneous modulus.**

Methods

Samples
➤ Skeletally mature animals
➤ Right and left joints
➤ Visually normal articular surfaces
  ▪ Tibial plateau
  ▪ Femoral condyles

Camera-registration system
➤ Articular surfaces were attached to a testing chamber filled with PBS and equipped with a camera-registration system (Biomomentum, Canada).
➤ A position grid was superimposed on the image of the sample (Fig. 1).
➤ Pixels into metric coordinates for the automated surface mapping.

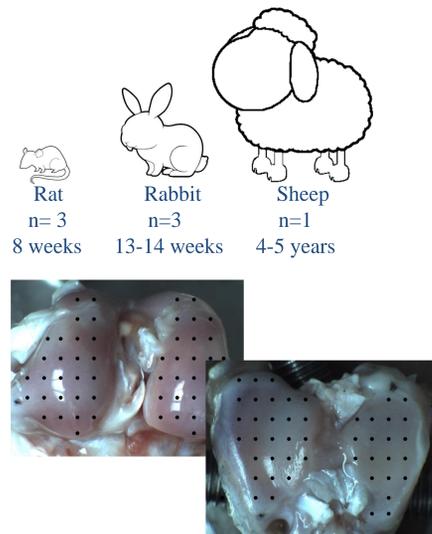Rat n=3 8 weeks — Rabbit n=3 13-14 weeks — Sheep n=1 4-5 years

Fig.1: Top view image of the articular surfaces (rabbit presented) with position grid superimposed.

Fig.2: 3-axis Mach-1 v500css mechanical tester (Biomomentum, Canada)

Automated Indentation
➤ At each position: a perpendicular indentation is performed by simultaneously moving the 3 displacement components (Fig. 2) based on the surface orientation and the resulting force is measured with a spherical indenter (r=0.5mm) placed on a multiaxial load cell.

Automated Thickness Measurement
➤ Needle probe (26G) replaces the spherical indenter.
➤ The thickness is obtained with an adapted version of the needle technique [2] with the indenter moving towards the surface.
➤ Cartilage surface corresponds to the position where the force starts to increase, the subchondral interface where the force increases steeply and the vertical thickness is the difference.

Thickness = Vertical thickness x cosine (surface orientation)

Fig.3: Vertical Load vs Displacement curve for thickness measurement and surface orientation

Extraction of the Instantaneous Modulus
➤ The Instantaneous Modulus at each position was obtained by fitting the load-displacement curve (Fig. 4) to an elastic model in indentation [3] using the measured thickness.
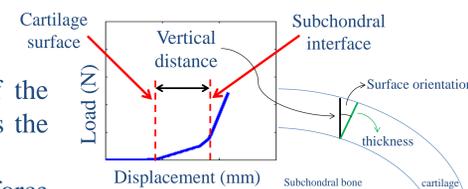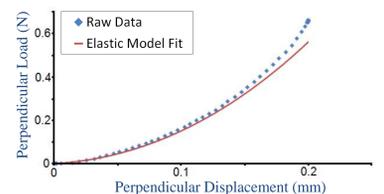
Fig.4: Perpendicular Load vs Displacement curve

Results

Thickness (mm)

	Rat	Rabbit	Sheep
Femoral Condyles	0.14±0.05	0.25± 0.09	0.83± 0.33
Tibial Plateau	0.14± 0.07	0.36± 0.20	0.71± 0.49

Instantaneous Modulus (MPa)

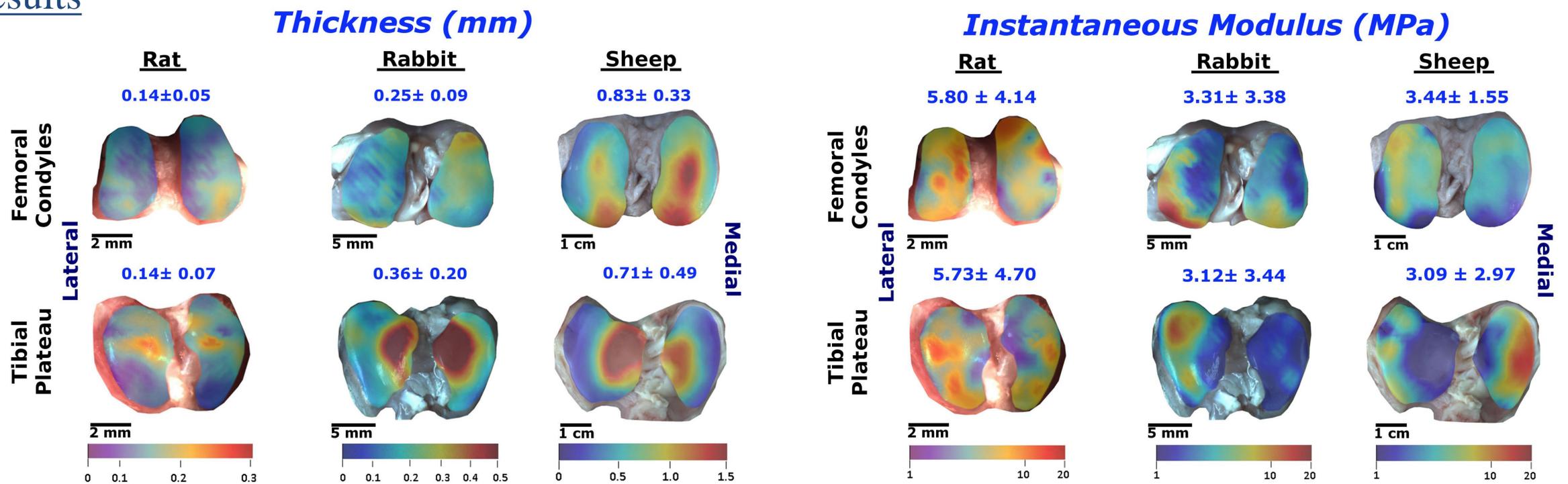|	Rat	Rabbit	Sheep
Femoral Condyles	5.80 ± 4.14	3.31± 3.38	3.44± 1.55
Tibial Plateau	5.73± 4.70	3.12± 3.44	3.09 ± 2.97

Fig.5: High-resolution mapping of the thickness and instantaneous modulus obtained on rat, rabbit and sheep articular surfaces.

➤ Spatial distribution of thickness and instantaneous modulus reveals a large variation within the medial and lateral compartment of femoral condyle and tibial plateau. This trend can be observed for all three species. Indeed, the cartilage is thinner and stiffer in regions covered by the meniscus while a thicker and softer cartilage is observed on the rest of the surface.

Discussion

➤ Measured thickness agrees with those reported in the literature [4].

➤ The instantaneous modulus mappings measured (Fig. 5) show similar distribution patterns than those previously observed for the stifle joints of larger species, with stiffer cartilage in the region covered by the meniscus [5], suggesting a dependence with weight bearing and kinematics [6].

➤ Cartilage thickness and instantaneous modulus can vary by a factor up to 10 over a distance of only 5% of the total articular surface width. These thickness and modulus maps clearly show that any difference between treated and non-treated cartilage could be confounded with the natural topographic variability rather than due to the treatment itself. By considering the spatial distribution of cartilage properties when choosing control and treated sites, the effects of treatment may be more easily discerned.

References: [1] Setton 1994, J Orthop Res **12**:451 [2] Jurvelin 1995, J Biomech **28**: 231 [3] Hayes 1972, J Biomech **5**:541 [4] Stockwell 1971, J Anat **3**:411 [5] Sim 2013, Trans ORS2013: poster 1975 [6] Fukubayashi 1980, Acta Orthop Scand **51**(6):871