Streaming Potential-Based Arthroscopic Device Discerns Topographical Differences in Cartilage Covered vs. Not Covered by Meniscus in Ovine Stifle Joints

A. Changoor°, E. Quenneville+, M. Garon+, L. Cloutier°, A. Légaré+, M.B. Hurtig**, M.D. Buschmann°

°Biomedical and Chemical Engineering Department, École Polytechnique de Montréal, Montréal, QC, Canada
+Bio Syntech Canada Inc., Laval, QC, Canada
**Comparative Orthopaedic Research Laboratory, University of Guelph, Guelph, ON, Canada

Introduction

• Animal models of osteoarthritis are used for understanding disease progression and are essential for assessing potential new therapies.

• Ovine models, such as the lateral meniscectomy model, are of interest because meniscectomy models often follow a disease progression similar to that in humans, and joint size is sufficient for multiple analyses of cartilage including biomechanical, biochemical & histological evaluations.

• Current evaluation methods do not allow for non-destructive, sequential, quantitative assessment of cartilage function.

• We have used a new arthroscopic device, the Arthro-BST™, to non-destructively evaluate cartilage at multiple positions in ovine knee joints.

Hypotheses

• User-independent evaluation of cartilage properties related to electromechanical function is possible with the Arthro-BST™.

• Differences in electromechanical properties in normal ovine cartilage in regions of the tibial plateau covered and not covered by meniscus can be assessed non-destructively using the Arthro-BST™.

Materials & Methods

A pair of stifle joints obtained from a 6 year old female sheep.

43 positions assigned on the tibial plateau & femoral condyles using a digital camera & software.

Streaming potentials measured during indentation, w/Arthro-BST™, & used to calculate the Quantitative Parameter (QP). Performed by 5 users making 3 measurements at each position.

4 mm diameter osteochondral cores harvested from 11 locations of the original 43 using a drill w/ hollow bit.

Cartilage thickness measured optically w/a stereomicroscope & software.

Unconfined compression testing using Mach-1™ Mechanical Tester: contact with cartilage surface, then 5 ramps of 2% amplitude applied at 0.4%/s. Between ramps, load decayed until 0.01g/min.

Data analysis: fibril modulus (Ef), matrix modulus (Em), and permeability (k) obtained with Fibril-network-reinforced biphasic model.

Statistical comparisons with a one-way ANOVA and Fisher’s LSD. Since the condyles articulate over the meniscus & tibial plateau, all measures of the femoral condyles were analyzed as one group.

Discussion & Conclusions

• Some variability among users could be attributed to user-specific differences in positioning the device on the relatively small cartilage surfaces and the broad range of mechanical properties and cartilage thickness observed on these joint surfaces.

• The mechanical properties measured in this study are consistent with mechanical measurements of cartilage on human tibial plateau, where thinner, stiffer cartilage was found in regions beneath the meniscus.

• Cartilage SPI maps, generated with the Arthro-BST™, were related to meniscal coverage in the sheep stifle.

• In future studies, additional parameters such as water content & collagen cross-links will be assessed to further describe the relationship between SPI and cartilage functional mechanical properties.

What are Streaming Potentials?

• During cartilage compression, positive mobile ions in the interstitial fluid are displaced relative to the fixed negatively charged proteoglycan molecules, which are entrapped in the collagen network (Fig. 3A).

• In osteoarthritic cartilage (Fig. 3B), the collagen network is degraded and there is a loss of proteoglycans, leading to abnormal streaming potentials.

Fig. 1: Arthro-BST™

Fig. 2: Mach-1™

Mechanical Tester

Table 1: Streaming Potential Integral (SPI), cartilage thickness, matrix modulus (Em), fibril modulus (Ef) and permeability (k) on the tibial plateau covered by meniscus (o), uncovered by meniscus (+) and on the femoral condyles (Δ). *+ indicate (p<0.05). All values are mean ± SEM.

<table>
<thead>
<tr>
<th>Parameter (QP)</th>
<th>Defined</th>
<th>Covered</th>
<th>Uncovered</th>
<th>Femoral Condyles</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI (mV*mm³)</td>
<td>24.2 ± 4.4*</td>
<td>1.0 ± 0.2*</td>
<td>12.5 ± 7.7</td>
<td></td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.2 ± 0.05*</td>
<td>0.57 ± 0.20*</td>
<td>0.5 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>Em (MPa)</td>
<td>0.2 ± 0.09</td>
<td>0.2 ± 0.1</td>
<td>0.5 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>Ef (MPa)</td>
<td>7.8 ± 3.2</td>
<td>6.1 ± 2.8</td>
<td>12.0 ± 2.4</td>
<td></td>
</tr>
<tr>
<td>k (mm²/Ns)</td>
<td>0.015 ± 0.014</td>
<td>0.0134 ± 0.010</td>
<td>0.0013 ± 0.0006</td>
<td></td>
</tr>
</tbody>
</table>

References: