•RELIABILITY AND CORRELATION TO HUMAN ARTICULAR CARTILAGE MECHANICAL PROPERTIES OF A STREAMING POTENTIAL BASED ARTHROSCOPIC INSTRUMENT

+**Garon, M; *Cloutier, L; **Légaré, A; **Quenneville, E; **Shive MS; *Buschmann, MD
+*Biomedical & Chemical Engineering, Ecole Polytechnique, Montreal, Quebec, Canada
garon@biosyntech.com

INTRODUCTION: Osteoarthritis (OA) is a common joint disorder that leads to articular cartilage destruction in lower extremity weightbearing joints like the knee, as well as hand joints. Age, obesity and knee injury are risk factors that increase OA incidence for the knee; OA prevalence is expected to increase by 57% by 2020 [1]. New pharmaceutical treatments are under development to prevent, delay or reverse progression of OA, however, no satisfactory clinical outcome measure to indicate cartilage health versus disease is currently available. Our objective is to provide a new medical instrument to satisfy this unmet need, by performing quantitative assessments of cartilage electromechanical properties during arthroscopy (Arthro-BST™, Bio Syntech Canada Inc.). The device has 37 microelectrodes evenly distributed over the surface of a 3.2 mm radius hemispherical indenter. The spherical tip is manually compressed against the articular surface and induced streaming potentials are recorded (Fig 1). The primary objective of this study was to evaluate the reliability of the measurement for multiple users and the secondary objective was to correlate measurements made with this arthroscopic device to standard biomechanical and geometrical properties.

METHODS: Human cadaveric samples. The Institutional Ethics Review Board approved the following protocol. The right knee of a 47-year-old woman with no history of chronic disease was frozen within 48 hours of death. Prior to dissection the knee was thawed at 4ºC for 72 hours. Then the trochlea, tibial plateaus and femoral condyles were harvested as cartilage-bone blocks and frozen. **Electromechanical testing with the Arthro-BST**. The cartilage surface was bathed in PBS and monitored in real-time using a digital video camera overlaying a user defined grid on the image. This grid was used to position manual indentation tests. 16 positions were tested on each tibial plateau, 24 positions on each femoral condyle and 22 positions on the trochlear surface. Cartilage at each position was manually compressed with the spherical Arthro-BST tip (~1 second) and streaming potentials were recorded with precise determination of compression amplitude, velocity and orientation via the software. All measured streaming potential signals were integrated *(Streaming Potential Integral, SPI)* over the hemispherical surface of the indenter in contact with the cartilage and over the displacement range 0.1 to 0.3mm. Each of five different users performed 3 consecutive mappings on each surface. **Unconfined compression testing & analysis.** Full thickness 8mm diameter cartilage disks (n=21) with a thin bone layer ~1mm were harvested after the manual indentation from positions that spanned a large range of measured SPI. Then, a 4mm diameter disk was punched and cartilage thickness measured using an optical microscope. Cartilage disks with a difference between maximum and minimum cartilage thickness lower than 20% were tested in unconfined compression in PBS with the Mach-1™ Mechanical Tester (Bio Syntech Canada Inc.). An initial pre-compression amplitude equal to the difference between the maximum and minimum thickness was applied followed by 5 stress relaxation ramps of 2% compression amplitude at 0.4%/sec with relaxation until the rate of load decay was less than 0.01g/min. The last stress relaxation ramp was fit to the fibril-reinforced biphasic model [2] to provide the equilibrium modulus (*Em*), the fibril modulus (*Ef*) and the permeability (*k*). **Statistical Analyses**. The reliability of the SPI measurements among different users was evaluated with the intraclass correlation coefficient ICC(2,1) [3] to compare the variability of measurements by different users at the same position versus to the total variation for all users and positions. Correlations between material properties and SPI were assessed by linear regression with the average SPI of the 5 users.

RESULTS SECTION: SPI measurement reliability. From the 102 measurements made in manual indentation, 10 positions produced signals below the detection level of the device. Figure 2 illustrates the variability between users of the remaining 92 SPI measurements, ordered by the average measured SPI. Each point represents the average of 3 measurements made by each user and the solid line is the average of the five users. The computed ICC was 0.87 indicating that interuser variability had a minimal effect on the measurement. **SPI correlation.** The streaming potential integral, SPI, correlated with both the cartilage fibril modulus, *Ef*, and cartilage thickness and the strongest correlation was obtained with the ratio *Ef*/Thickness (Fig 3). Contour line plots of SPI values overlayed on images of the articular cartilage surfaces displayed reproducible patterns that depended on the particular joint surface (condyle vs tibial plateau), central versus peripheral sites, and sites that were covered vs uncovered by the meniscus (Figure 4 A is a lateral femoral condyle and B is a tibial plateau before meniscus removal, where points represent the manual indentation positions).

DISCUSSION: The high value of the intraclass correlation coefficient (0.87) demonstrates the ability of the Arthro-BST to provide user independent cartilage electromechanical properties and was superior to previously published values using a dynamic indentation probe [4]. The correlation of SPI with fibril modulus and cartilage thickness agreed with a previous study in the equine stifle joint [5]. The strong dependence of the SPI of tibial plateaus on proximity to the meniscus is also in agreement with a previous study showing lower human cartilage stiffness in regions not covered by the meniscus compared to covered by the meniscus [6]. Taken together, the large dynamic range of the SPI (Fig 2), combined with its minimal user dependence, and ability to precisely reflect regional and site dependent variations of articular cartilage bode well for the use of the Arthro-BST as a clinical outcome measure to indicate cartilage health versus disease. Ongoing studies target the completion of a database of cartilage electromechanical properties using multiple cadaver knees and the initiation of clinical studies to monitor these properties in relation to joint disease processes.

Figure 1 - Arthro-BST



Figure 2 - Inter-User Reliability

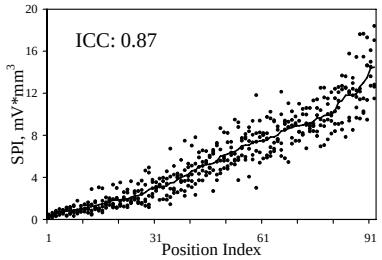


Figure 3 - Streaming Potential Integral vs Fibril Modulus / Cartilage Thickness

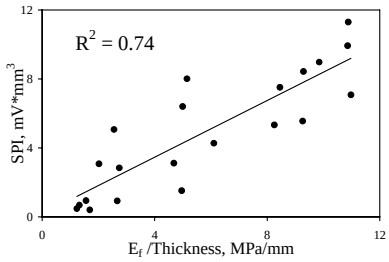
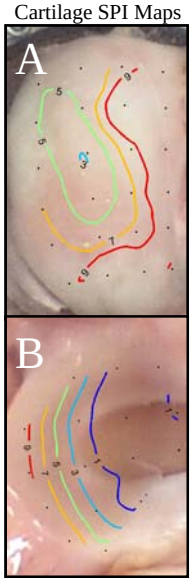


Figure 4
Cartilage SPI Maps



ACKNOWLEDGEMENTS: Natural Sciences and Engineering Research Council of Canada and Bio Syntech Canada Inc.

REFERENCES: [1] Felson, Osteoarthrits, Oxford University Press, 13-22, 1999. [2] Soulhat *et al., J Biomech Eng*, 121:340-347, 1999. [3] Shrout *et al., Psychological Bulletin*, 86:420-428, 1979.[4] Appleyard et *al., Phys. Med. Biol.*, 46 :541-550, 2001.[5] Garon *et al., Trans Orthop Res Soc*, 28:255, 2003.[6] Thambyah *et al., Osteoarthritis and Cartilage*, 14:580-588, 2006.

** Bio Syntech Canada Inc., Laval, QC, Canada