

ARTHROSCOPIC DEVICE MEASURING STREAMING POTENTIALS RELIABLY INDICATES FUNCTIONAL PROPERTIES OF CARTILAGE

M. Garon¹, A. Légaré¹, É. Quenneville¹, T. J. Sims², A. P. Hollander², M. S. Shive¹, A. Restrepo¹, M. D. Buschmann³

¹Bio Syntech Canada Inc., Laval, QC, CANADA,

²University of Bristol Academic Rheumatology, Bristol, UNITED KINGDOM,

³Biomedical & Chemical Engineering, Ecole Polytechnique, Montreal, QC, CANADA.

INTRODUCTION

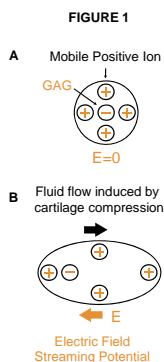
Pharmaceutical treatments are under development to prevent, delay or reverse progression of OA. However, no generally accepted clinical outcome measure to indicate cartilage health versus disease is currently available. Our objective is to provide an arthroscopic device, the Arthro-BST™, which measures cartilage streaming potentials in order to evaluate the efficacy of new treatments and to help surgeons to more precisely identify areas of damaged cartilage during arthroscopic procedures.

HYPOTHESES

The streaming potentials measured with the instrument are i) reliable among multiple users and ii) correlate with standard biomechanical, biochemical and topographical properties of human articular cartilage.

ORIGIN OF STREAMING POTENTIALS

In cartilage, the proteoglycan aggrecan is entrapped in a collagen fibril network. Due to the negative charge of the glycosaminoglycans (GAG) on aggrecan, there is an excess of mobile, non-fixed, positive ions in the fluid. Under equilibrium conditions (Figure 1A), with no load or fluid flow, these positive charges are symmetrically arranged so that no net macroscopic electric field exists. During fluid flow induced by cartilage compression (Figure 1B), there is a displacement of positive ions relative to the fixed charge of GAG resulting in an electrical field called streaming potential.



INSTRUMENT

The Arthro-BST™ (Figure 2) is a hand-held medical device designed to be used during an arthroscopic procedure to measure compression-induced streaming potentials of articular cartilage. The device sensor has 37 microelectrodes evenly distributed over the surface of a spherical indenter (Figure 3). Streaming potentials are recorded by each microelectrode when the spherical indenter is manually compressed against the articular cartilage surface. The device detects how many and which electrodes are touching the cartilage to determine the amplitude and orientation of the sensor during cartilage compression. Streaming potentials are then analysed taking into account this detected amplitude and orientation. Consequently, the analysed streaming potentials are independent of the force applied and of the orientation of the sensor.



FIGURE 2



FIGURE 3

METHODS

Cartilage Mapping. The trochlea, tibial plateaus and femoral condyles were harvested as cartilage-bone blocks from a cadaveric knee of a 47-year-old woman. These blocks were immersed in PBS and 5 different users performed 3 consecutive mappings on each cartilage surface with the Arthro-BST™.

Biomechanical and Biochemical Analyses. Full thickness 4mm diameter cartilage disks with a thin bone layer were harvested from mapped cartilage surfaces. Stress relaxation testing was performed on cartilage disks in unconfined compression. The results were fitted to the fibril-reinforced biphasic model [1] to provide the equilibrium modulus, the fibril modulus and the permeability. Cartilage disks were also analyzed for the contents of collagen and both mature and immature collagen crosslinks [2].

Statistical Analysis. The reliability of the streaming potential measurements among different users was evaluated with the intraclass correlation coefficient (ICC) [3]. Correlations between material properties and streaming potentials were assessed by linear regression using the averaged measurement of the 5 users.

RESULTS

Instrument Reliability. The computed ICC was 0.87 indicating that interuser variability had a minimal effect on the measurement.

Correlation of Streaming Potentials to Biomechanics and Biochemistry. The streaming potential measurements obtained with the instrument correlated with cartilage fibril modulus (Fig. 5), cartilage thickness, collagen content (Fig. 6) and the ratio of mature to immature crosslinks (Fig. 7).

Cartilage Mapping. Surface maps of the streaming potential measurements overlaid on corresponding images of the articular cartilage surfaces (Fig. 4) displayed patterns that depended on the particular joint surface, central versus peripheral position, and on whether the cartilage was covered or not covered by the meniscus. While the maps of tibial plateaus under menisci displayed symmetric and regular patterns, the maps of opposing femoral condyles were less regular. The lower values of the streaming potential measurements on the medial condyle (blue regions in Fig. 4) surrounded a visible lesion (red star on Fig. 4) but extended beyond the visible lesion to possibly indicate the extent of incipient cartilage degeneration.

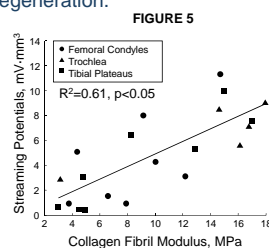


FIGURE 5

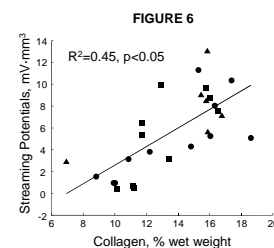


FIGURE 6

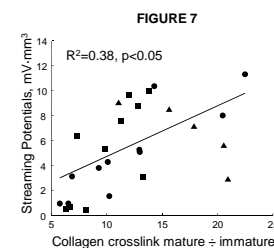


FIGURE 7

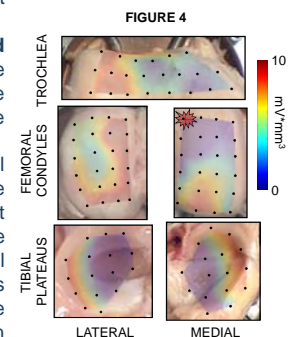


FIGURE 4

CONCLUSION

Streaming potentials measured with this device on human articular cartilage correlate well with biomechanical and biochemical properties related to collagen. We demonstrated that this indicator was user-independent and can detect local cartilage degeneration. The strong dependence of the streaming potential measurements of tibial plateaus on proximity to the meniscus is in agreement with a previous study showing lower human cartilage stiffness in regions not covered by the meniscus compared to those covered by the meniscus [4]. These promising results to date demonstrate the potential for clinical use to quantify cartilage properties on different joint surfaces during arthroscopy, as well as for an outcome measure to evaluate OA therapies. The Arthro-BST™ is not yet approved for sale by the FDA in the USA.

ACKNOWLEDGEMENTS: Natural Sciences and Engineering Research Council of Canada

REFERENCES: [1] Soulhat et al., J Biomech Eng, 121:340-347, 1999. [2] Sims et al., Extracellular matrix protocols, 139:11-26, 2000.

[3] ShROUT et al., Psychological Bulletin, 86:420-428, 1979. [4] Thambayah et al., Osteoarthritis and Cartilage, 14:580-588, 2006.