• Streaming Potential-Based Arthroscopic Device Detects Cartilage Changes Immediately Following Impact in an Equine Model of Osteoarthritis
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Introduction: Post-traumatic osteoarthritis (PTOA) develops some time after acute injury or trauma and can lead to loss of joint function and pain. Because the initiating event is known, a unique opportunity exists during the early stages of the disease where therapeutic intervention may be used to mitigate disease progression [1]. Impact models are ideal for studying potential therapeutic strategies because the location and severity of impact to the joint surface can be controlled. In particular, equine models are advantageous because the large stifle (knee) joints make arthroscopic access to regions on the trochlea possible and the cartilage is relatively thick. However, current cartilage evaluation methods may be inadequate for detecting subtle changes occurring during early PTOA. Streaming potentials, generated during cartilage compression, are a sensitive measure of degeneration [2] and may be valuable in this regard. The Arthro-BST®, a commercially available arthroscopic device, non-destructively measures the electric potentials generated during cartilage compression. An array of microelectrodes on a hemispherical indenter is lightly compressed against articular cartilage and a Streaming Potential Integral (SPI) is computed that reflects cartilage function, structure and composition. The objectives of this study were to evaluate the ability of streaming potentials to detect cartilage changes immediately following different levels of impact stress, and to assess sensitivity compared with biomechanical testing.

Methods: Both stifles from a 4 year old Standardbred horse with no pre-existing joint pathology were collected within 1 hour of sacrifice and stored at 4°C. 36 sites per trochlea were identified on the lower two-thirds of the joint surface by using a camera and software. The Arthro-BST® device was used to compress cartilage at each site by two users who made three measurements at each site. Impacts, at one of three stress levels, were delivered randomly to 24 sites using a custom-built impactor device, consisting of a spring loaded shaft and sterilizable, 6.5 mm diameter plane-ended tip with rounded edges, designed specifically for use in both in vitro and in vivo studies [3]. Impact stresses were derived from measurements made with a calibrated piezoelectric force transducer in-line with the impactor tip. The remaining 12 sites served as non-impacted controls. Immediately following impacts, India ink was applied and electromechanical measurements repeated. Osteochondral cores were extracted manually from all 36 sites and stored in humid chambers at 4°C for biomechanical testing in unconfined compression geometry on a Mach-1 Micromechanical Tester. Immediately prior to testing, cartilage was separated from the underlying bone, re-punched to 3 mm diameter, and equilibrated in PBS. Cartilage thickness was measured with an upright digital micrometer. Each disk was subjected to five stress relaxation ramps of 2% strain. The fibril-network-reinforced biphasic model was fit to the data to obtain fibril modulus (Ef), matrix modulus (Em) and hydraulic permeability (k) [4]. Paired t-tests were used to compare pre- and post-impact SPI, while a one-way ANOVA and Fisher’s LSD were used to compare biomechanical parameters at impacted versus control sites. Correlations between SPI and biomechanical properties were calculated (Statistica v.9).

Results: Different cartilage thicknesses and functional properties were exhibited on the lateral compared to the medial facets of the equine trochlea (Tables 1&2). Impacts were either low, 17.3±2.7 MPa (n=15), medium, 27.8±8.5 MPa (n=13), or high, 48.7±12.1 MPa (n=16), where low was slightly higher than physiological [5] and high leads to osteoarthritis progression [3]. India ink revealed extensive surface cracking and diffuse staining at high impact sites compared with no or faint staining at low impact sites. Medium impact caused variable changes ranging from faint staining to minor cracking. Mean SPI measurements were in excellent agreement between users with a correlation of r=0.918 (p<0.0001, n=144), confirming that this method is user-independent. When compared to pre-impact values, SPI was significantly reduced at high (p=0.003, n=16) and medium (p=0.003, n=16) impact sites, but not at low impact sites (p=0.473, n=16) (Fig.1). High impact samples had reduced Ef, representing collagen network stiffness (p<0.001 for lateral and p=0.026 for medial), coupled with increased permeability (p=0.003 for lateral and p=0.002 for medial). A trend towards a decrease in Ef was detected in medium impact samples (p=0.074). No statistically significant changes in Em, representing proteoglycan matrix stiffness, were found, however trends were observed on the medial surface for high (p=0.085) and medium (p=0.076) impacts. Linear regression analysis identified correlations between SPI and cartilage thickness (r=-0.814, p<0.0001, n=75), and SPI and Ef (r=0.754, p<0.0001, n=75), further establishing the relationship between non-destructive, electromechanical measurements and intrinsic cartilage properties.

Discussion: Controlled impacts were successfully delivered to the articular surfaces resulting in varying degrees of cartilage damage. The data suggests that high impacts (and to a lesser extent, medium impacts) cause immediate, measurable damage to the collagen network but there is insufficient time for detectable proteoglycan loss to occur. Both electromechanical and biomechanical methods detected cartilage changes following high impact, however only SPI measurements perceived changes due to medium impact, indicating a greater sensitivity of electromechanical measurements. In summary, streaming potentials were more sensitive to changes in cartilage following impact than biomechanical measurements, as seen previously [6, 2]. The non-destructive nature of the streaming potential method would make sequential assessment of cartilage over time possible for in vivo models where initial degeneration is focal but that could progress to gradually involve more of the articular surface. Such a model could be used to evaluate the efficacy of therapeutic agents to slow or prevent osteoarthritis.

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