Non-Invasive Electroarthrography and Centre of Pressure Measurements Track Progression in an Equine Chip Model of Early Osteoarthritis

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INTRODUCTION: Osteoarthritis (OA) is a disease of articular joints characterized by progressive cartilage degradation. Low-grade, asymptomatic cartilage deterioration occurs early in the disease process, however, clinical assessments, including radiographs and physical examination, are unable to detect these subtle changes. Objective monitoring of early OA may identify opportunities for interventions with potential to slow OA progression. Electroarthrography (EAG) is the non-invasive measurement of cartilage streaming potentials, which arise from the response of the hydrated cartilage extracellular matrix to compressive loading and correlate to biomechanical properties, histological scoring and biochemical composition. EAG is measured through electrodes placed on the skin surrounding an articular joint and has been used to assess cartilage in human knees [1] and equine metacarpophalangeal joints [2]. EAG is acquired during joint loading and biomechanical parameters may offer critical insights into EAG signal generation. For example, centre of pressure (COP) denotes the point on the joint surface at which ground reaction force (GRF) is concentrated. This study aims to determine if EAG and COP can be used to track the progression of early osteoarthritis in an equine metacarpophalangeal chip model, where an osteochondral fragment is surgically created that, when combined with a post-operative exercise regime, induces change to cartilage, subchondral bone, synovium, and the development of osteophytes that mimic OA.

METHODS: Procedures were performed on 6 Standardbred horses (12-17 years old, 467-520 kg) with Institutional Animal Care Committee approval (University of Guelph, AUP#4616). Each horse underwent surgical creation of an osteochondral chip on the medial aspect of the proximal phalanx and post-operative treadmill running 15 minutes daily, 5 times per week for the remainder of the study. Six weeks after surgery, horses were assigned to intra-articular treatment with a biologic (n = 3) or saline (n = 3). EAG and simultaneous biomechanical measurements were collected 1 week prior to surgery as well as 3, 5, 9, and 11 weeks after surgery. EAG was performed on the metacarpophalangeal joint using adhesive electrodes (Red Dot 2560, 3M) placed at dorsal, medial and lateral positions around the metacarpus-phalanx interface. GRF and COP were measured with a custom-made array of 12 force sensors (FlexiForce A502, Tekscan) placed underneath the hoof. Joint loading consisted of 10 cycles where the contralateral leg was lifted to shift weight to the instrumented forelimb, held aloft for 5 seconds, and released. EAG signal amplitudes, GRF and COP were obtained from the last 5 loading cycles using custom MatLab code. To facilitate comparisons, EAG from the three electrodes in closest physical proximity to the surgical chip were combined (EAG_{comb}). Lameness was quantified using a kinematic assessment tool (Equinosis One) that tracks movement of the head, pelvis and front leg to calculate a vector sum related to lameness in millimeters. A one-way ANOVA with Tukey's post-hoc tests were used to compare EAG signals, COP and Equinosis lameness vector sum (SPSS v.28).

RESULTS: Compared to pre-operative baseline data, EAG_{comb} was significantly lower in 4 out of 6 horses 3 weeks after surgery ($0.001 < p < 0.012$) and in all horses 5 weeks after surgery ($0.001 < p < 0.013$), coinciding with the establishment of early OA (Figure 1). Similarly, all horses exhibited significantly higher lateral COP movement 5 weeks after surgery, compared to baseline (Figure 2. Biologic: $p < 0.001$, Saline: $p = 0.026$). After biologic treatment, EAG_{comb} was significantly higher at 11 weeks, compared to week 5, in all three horses ($0.001 < p \leq 0.003$), however trends in the saline group were inconsistent with some horses showing an increase in EAG_{comb} closer to baseline and others remaining below baseline. The saline group maintained significantly higher lateral COP movement 11 weeks after surgery ($p < 0.001$), while those treated with biologic were not significantly different than baseline ($p = 0.462$). EAG_{comb} was strongly correlated to the vector sum of lameness in 3 out of 6 horses (2 of 3 received biologic), moderately correlated in 2 out of 6 horses (both received saline), and weakly correlated in one horse who received biologic (Table 1 & Figure 1). The magnitude of lateral change in COP was strongly correlated with lameness vector sums in 4 out of 6 horses (Table 1).

DISCUSSION: Both EAG and COP successfully tracked the development of early OA induced by the chip model, which is reported to produce mild to moderate articular lesions [3] (Figures 1 & 2). Treatment with biologic effectively returned EAG and COP to baseline, however only COP remained different than baseline in the saline treated group (Figures 1 & 2). Interpreting the EAG results for the saline group requires consideration of the elevated ages of these horses [4] and evidence of pre-existing cartilage degradation observed during surgery (data not shown). The addition of MRI and arthroscopy scores are expected to contribute to a better characterization of cartilage quality and thereby improve interpretation of EAG data in this group. The lameness vector sum agreed with EAG and COP results (Table 1) and can detect lameness in individual limbs [5], although it cannot determine if lameness is caused by cartilage or other musculoskeletal tissues. EAG reflects intrinsic cartilage properties [2] as well as external factors like joint loading mechanics. The COP results indicate that COP may be an important factor to integrate into EAG analysis since changes to the COP pattern modifies the joint pressure distribution and contact area [6] and likely influences the creation and propagation of streaming potentials during joint loading. Despite the small sample size, this study demonstrated that EAG, a non-invasive method for assessing cartilage quality, can track the progression of early OA and subsequent cartilage changes due to treatment.

SIGNIFICANCE/CLINICAL RELEVANCE: EAG, a non-invasive method for assessing cartilage quality, tracked progression of early OA and subsequent cartilage changes due to treatment. These data support the development of EAG into a clinical methodology for the monitoring and diagnosis of osteoarthritis and other degenerative joints diseases.

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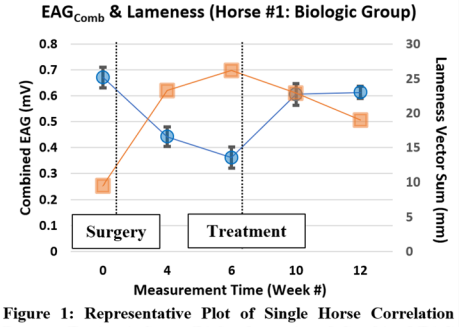

Figure 1: Representative Plot of Single Horse Correlation Between Equinosis Score (Right, Orange) and Combined EAG (Left, Blue). Error bars show standard error.

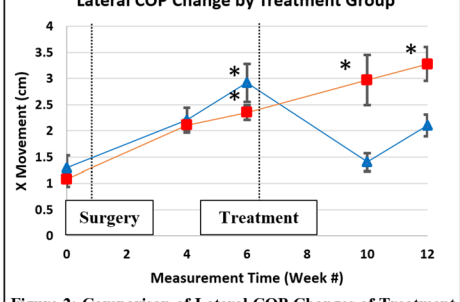

Figure 2: Comparison of Lateral COP Changes of Treatment (Blue) and Saline (Red) Groups. (*) - Significant Differences ($p<0.05$) to Baseline. Error bars show standard error.

Table 1: Pearsons Correlation (r) Between Lameness Scores and Combined EAG and Lateral Change in COP.

Horse # (Group)	Combined EAG	ΔX COP
1 (Biologic)	-0.790 (p=0.112)	0.732 (p=0.159)
2 (Biologic)	-0.201 (p=0.746)	0.850 (p=0.068)
3 (Biologic)	-0.613 (p=0.272)	0.744 (p=0.149)
4 (Saline)	-0.534 (p=0.353)	0.302 (p=0.622)
5 (Saline)	-0.689 (p=0.198)	0.688 (p=0.199)
6 (Saline)	-0.575 (p=0.310)	0.114 (p=0.855)