Associations between multi-joint data driven biomechanical features extracted during walking and hip cartilage degeneration changes from quantitative MRI

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INTRODUCTION: Gait characteristics, cartilage biochemistry, and demographics are likely to have complex interactions that act as risk factors for hip osteoarthritis (OA). Gait studies are often limited to biomechanical evaluations at singular time points, thereby disregarding substantial amounts of data. Where many radiographic or symptomatic hip OA diagnosis techniques are semi-quantitative, quantitative magnetic resonance (MR) imaging can provide direct measures of cartilage biochemistry. Increased $T_{1\rho}$ and T_2 relaxation times correspond to decreased proteoglycan content and increased water content and matrix disorganization, respectively. In this study, we used a data-driven approach to identify key features of multi-joint lower-limb kinematics that are associated with quantitative measures of cartilage degeneration.

METHODS: Seventy-two subjects (41 female; age: 51.4 ± 14.9 yo; BMI: 24.3 ± 3.3 kg/m²) with varying degrees of hip OA (Kellgren-Lawrence scores of 0-3) signed informed consent. Bilateral hip images were acquired on a 3T MR scanner (GE Healthcare) using a 32-channel coil (GE Healthcare). A combined $T_{1\rho}$ and T_2 sequence was used to quantitatively assess the cartilage matrix. Acetabular and femoral cartilage were automatically segmented using a single atlas-based approach. Mean $T_{1\rho}$ and T_2 relaxation times were calculated across all acetabular and femoral cartilage voxels. Skin marker trajectory data was acquired with a 10 camera near-infrared system (Vicon, Oxford Metrics LTD.) at 250 Hz as subjects walked at 1.35 m/s. Trajectory data were filtered with a fourth order, zero lag, low-pass Butterworth filter at 6 Hz (Visual3D, C-Motion). Hip, knee, and ankle joint angles were calculated (Visual3D) and combined to create a multivariate functional data object for each plane. Multivariate functional principal component (MFPC) analysis of each planar data object was used to identify the first 10 MFPC modes of variation.[1] A step-wise linear regression model related demographic features and MFPC modes to mean $T_{1\rho}$ and T_2 relaxation times (R Development Core Team, v3.3.3). Significance was set at $p < 0.05$. Results were reported as (estimate; p value).

RESULTS: In the femoral cartilage, transverse MFPC 3 with 15.3% of variance (-0.020; p = 0.015) and BMI were significantly related to $T_{1\rho}$ relaxation times, while transverse MFPC 2 with 24.6 % of variance (0.026; p = 0.005) and BMI were significantly related to T_2 relaxation times (**Figure 1**). In the acetabular cartilage, sagittal MFPC 1 with 69.3% of variance (0.008; p = 0.013) and BMI were significantly related to $T_{1\rho}$ relaxation times, while coronal MFPC 1 with 57.2% of variance (-0.019; p = 0.026), transverse MFPC 1 (**Figure 1**) with 39.7% of variance (-0.014; p = 0.042), and BMI were significantly related to T_2 relaxation times.

CONCLUSIONS: Many of the MFPC modes significantly related to cartilage relaxation times were in the transverse plane, which suggests that transverse plane kinematics are more likely connected to hip OA than motion in other planes. Specifically, increased hip, ankle, and knee internal rotation, were indicative of increased relaxation times in the femoral cartilage. Furthermore, this study established a data-driven framework to assess relationships between multi-joint biomechanics and quantitative assessments of cartilage biochemical composition.

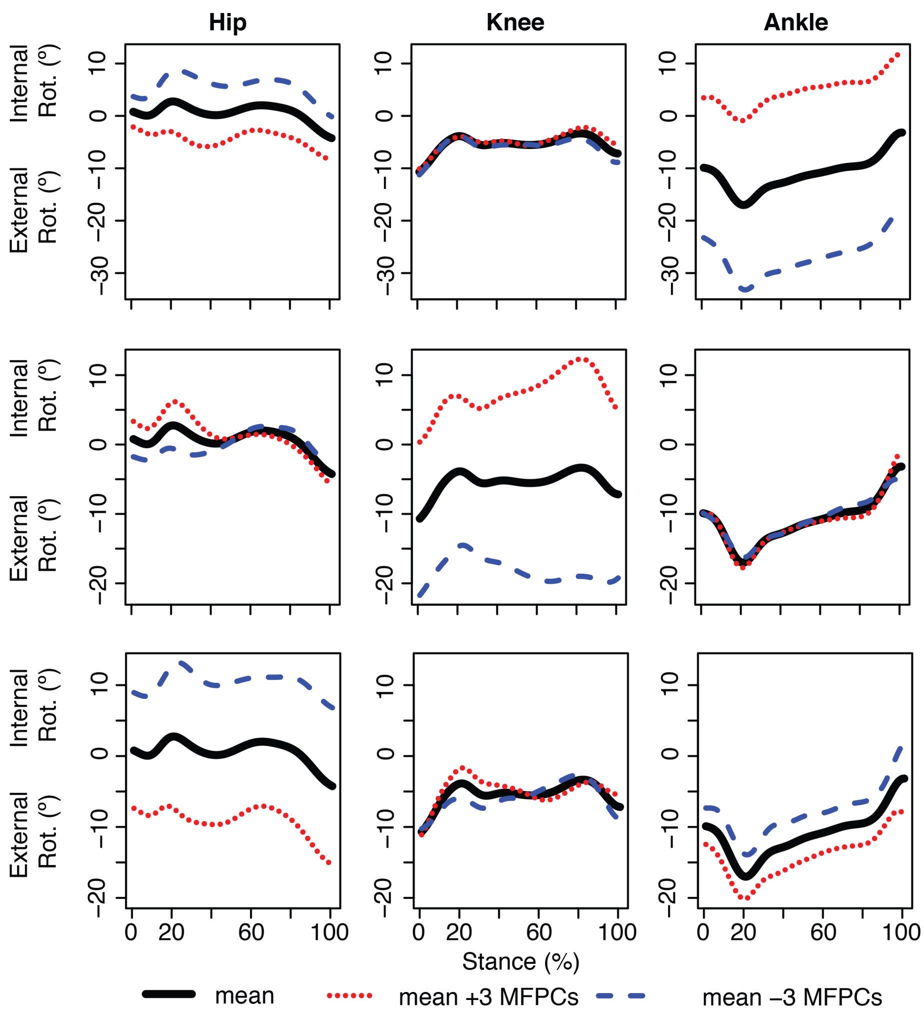

Figure 1: Mean hip (left), knee (center), and ankle (right) angles plus or minus three multiples of transverse plane multivariate functional principal components (MFPCs) 1 (top), 2 (middle), and 3 (bottom). Internal rotation is positive. Rot = rotation.

REFERENCES:

1. Happ C, Greven S. Multivariate Functional Principal Component Analysis for Data Observed on Different (Dimensional) Domains. *Journal of the American Statistical Association.* 2018;113(522):649-659.