INTRODUCTION:
Low back pain (LBP) is a leading cause for physician visits in the United States, ranked 2nd behind upper respiratory conditions. Costs associated with LBP exceed $100 billion annually, the majority of which are due to imaging costs. In mechanical LBP, the symptoms are related to mechanical trauma or degeneration resulting from activities, including those from daily living.

Past efforts have used spinal kinematics and kinetics to understand the biomechanical factors associated with the clinical presentation of the patient, though these efforts are difficult to reproduce and many are subject to measurement validation issues. In addition, while it is known that range of motion (ROM) is associated with aging and decreased mobility, quantifying ROM is not suitable for differentiating pathology in the lumbar spine.

This work tracks in-vivo motion of the lumbar spine at the L1 to L5 vertebrae for 40 patients during three activities. A novel motion coefficient was defined, quantifying the overall path of motion. This work examines whether these new coefficients can be related to underlying lumbar pathology.

METHODS:
40 patients underwent CT and MRI examinations. Additionally, each patient was asked to perform three activities, moving from the point of maximum flexion to maximum extension, lateral bending and axial rotation. Digital fluoroscopy was used to record each activity. 20 patients were diagnosed as healthy or healthy with LBP, with no radiological evidence of lumbar degeneration or defects of the lumbar spine. The remaining patients were classified as degenerative, and had experienced pain prior to evaluation and radiologically exhibited one or more of the following conditions: Schmorl’s Nodes, disc bulging both with and without canal or foraminal stenosis, disc osteophyte complexes, decreased height and fluid signal in the intervertebral disc, or facet hypertrophy. Institutional Review Board approval was obtained as well as informed consent for all patients participating in this study under IRB #7393 & #070883.

Path specific bone representations were segmented from CT for the L1 to L5 vertebrae. The 3D models were registered to the fluoroscopy frames using a previously develop 3D-2D registration technique, seen in Figure 1. In vivo kinematics were determined by interpolating for the motion between registered frames using shape preserving cubic Hermite polynomials. This method was previously validated for the cervical spine as well as other joints (knee, hip, etc.). Path of rotation (POR) were determined for the in plane motion and complex out of plane motions at each functional unit of the lumbar spine for each activity. POR was calculated as summation of the absolute difference between each frame across the entire activity.

The coefficients of the motion are calculated as the ratio of the amount of in plane POR to the amount of out plane POR between the L1 and L5 vertebrae for each activity. Statistical analysis was performed using the non-parametric Mann-Whitney test.

RESULTS SECTION:
The 40 patients were divided into 2 groups, 20 healthy or healthy with LBP based on radiological evaluation (H group) and 20 degenerative based on the radiological criteria (D group). The three coefficients of motion were calculated for the activities of flexion-extension, C_{FE}, lateral bending, C_{LB} and axial rotation, C_{AR} using the POR ratios. For the healthy patients (mean age: 40.67 ± 11.65), the mean C_{FE} was 0.448 ± 0.408, the mean C_{LB} was 1.097 ± 0.45 and the mean C_{AR} was 2.577 ± 0.649.

The D group (mean age: 44.33 ± 10.55) results were mean C_{FE} of 1.164 ± 0.386, mean C_{LB} of 2.302 ± 0.679, mean C_{AR} of 3.282 ± 1.288.

The distributions of the coefficients for C_{FE}(p<0.001, two-tailed) and for C_{AR}(p<0.001, two-tailed) differed significantly between patient groups. The motion coefficient for axial rotation, C_{AR}(p>=0.05, two tailed), showed no statistically significant differences between patient groups. Figure 2 shows the mean and standard deviations of the coefficients.

DISCUSSION:
Our results indicate that the coefficients showed statistically significant difference between patients who would not normally require diagnostic imaging (H group) and those who would require imaging for diagnoses (D group), using C_{FE} and C_{LB}. POR for axial rotation activity suggest no significant differences between patient groups. Previous work has shown no significant relationship between degeneration and lumbar ROM, but ROM measurements are limited to the starting and ending locations and fail to account for the path of motion. Using the POR of the in plane motion and out of plane motions, these coefficients represent a simple quantification of the path of motion and, if easily approximated in a clinical setting, may prevent unnecessary diagnostic imaging.

This study was limited by a small sample size, and future work should seek to validate this result on larger sample sizes and determine methods for easily approximating POR.

SIGNIFICANCE:
This study introduces a new method for quantifying motion of the lumbar spine in the form of motion coefficients based on path of rotation (POR). This work suggests that these coefficients may hold potential for differentiating lumbar pathology using measurements of patient motion.

ACKNOWLEDGEMENTS:
This publication was made possible by grant number 5R01AR055882 from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) at the National Institutes of Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIAMS. We thank Christopher Carr, Joseph Mitchell and Nicholas Battaglia for their support in this work.

Figure 1. Patient specific representation overlayed onto the fluoroscopy frames using the 3D-2D registration technique.

Figure 2. Results for motion coefficients C_{FE}, C_{LB} and C_{AR} for patients from both groups.