Introduction: To understand the biomechanical factors that cause degenerative changes in the lumbar spine, it is critical to accurately determine the lumbar spine function under various physiological loading conditions. However, due to the limitations of current technology and the complicated anatomy of the spine, limited in-vivo data has been reported on lumbar spine motion [1][2]. Recently, we developed a combined dual fluoroscopic and MR/CT imaging technique for measurement of in-vivo 6 degree-of-freedom (6DOF) dynamic spine kinematics non-invasively. In this paper, we presented a rigorous validation of accuracy and reliability/repeatability of the imaging method and an application on a living human subject.

Materials and Methods: An intact ovine lumbar spine specimen was used for accuracy validation of our imaging method for measurement of spine kinematics. The spine was CT and MR scanned and the contours of L2 and L3 were digitized to create 3D vertebral models. The specimen was then bonded to an MTS machine which moves at 1000 mm/min and dynamic images at 30 frames/second were taken using two fluoroscopes that positioned perpendicular to each other. The specimen was then manually flexed and extended to simulate dynamic motion of the spine and dynamic images were also taken using the fluoroscopes.

The geometry of the fluoroscopes was reproduced virtually in a solid modeling software, Rhinoceros. Pairs of fluoroscopic images were placed at the two virtual intensifiers. The CT/MRI models of the vertebras were introduced into the virtual system and viewed from the perspective views of the virtual sources. The 3D models were then independently moved and rotated in 6DOF until their outlines matched the osseous outlines of the fluoroscopic images from the two orthogonal views.

To evaluate the accuracy, 2 spine positions were chosen from the MTS test. Both the CT and MRI models were used to reproduce the spine positions 5 times independently. The displacements and speeds of L2 and L3 were calculated and compared to those of the MTS machine. To evaluate the repeatability, positions along the flexion path were matched 5 times using both the CT and MRI models. The 6DOF kinematics were expressed using x, y and z for left/right hand, anterior/posterior and up/down translation and using α, β and γ for flexion/extension, medial/lateral bending and internal-external rotation. The mean and standard deviations (SD) for these matching trials were analyzed.

Finally, this technique was used to determine the lumbar vertebras (L2, L3) positions of a living subject. Only MR models were obtained to minimize the radiation exposure. Four postures were imaged using the dual fluoroscopes: standing, maximal left/right twist, and forward flexion at approximately 45°. The positions of the L2 and L3 were reproduced 5 times for each posture to investigate the repeatability in reproducing in-vivo vertebral kinematics. The differences in translation and orientation of the vertebras were then analyzed.

Results: The technique showed a high accuracy in determination of displacement and speed of the spine. Between the two positions, the displacement errors were within 0.3 mm and the speed errors range within 0.1 mm/s for both CT and MR models. The technique was highly repeatable to determine dynamic spine motion. For the CT models, the average SD was 0.1mm for translation and 0.3 mm for rotation; for the MR models, the average was 0.2mm and 0.5° in determination of the vertebral positions in space during the dynamic flexion/extension motion. Accuracy validation using MTS machine For the living human subject, on average, the position was determined with a SD of 0.2 mm and orientation with a SD of 0.4° for both vertebra and 0.3 mm and 0.6° for relative motion of the L2 with respect to L3. Repeatability, CT and MRI for ovine spine and in-vivo patient data

Discussion: The data demonstrated that this new imaging matching method carried excellent repeatability and accuracy in determining 6DOF vertebral kinematics. The MRI based spine model had a similar accuracy compared the CT based mode. A notable advantage using the MRI based model was the capability of studying various physiologic motions of living subjects with minimal radiation dosage.

This system can be used as a non-invasive method to measure pathological vertebral motion, such as disc degeneration, scoliosis and spondylolisthesis, and also the effect of surgical interventions (such as spine fusion or artificial disc replacement) on spine function. Therefore, this image matching method provides a powerful tool for investigating spine motion with or without pathology and for improving surgical modalities of disease treatment.