Three-dimensional, non-invasive, in-vivo studies were performed for evaluation of weight bearing knee kinematics using custom high resolution (1.5T) MRI protocols. Using 3D reconstructions, tibia motion relative to the femur and flexion angle was measured. Tibio-femoral contact area of the medial and lateral compartments was examined as well. Knee motion, evaluated from 0 to 60 degrees of flexion revealed increasing tibial internal rotation, tibial valgus, knee joint compression, and femoral roll-back with increasing flexion angle. Medial-lateral translation did not change significantly, and both medial and lateral contact areas decreased with flexion.

Introduction: Previous studies of knee biomechanics and cartilage contact have been limited by invasiveness [1], two-dimensionality [2], accuracy of marker position [3], or lack of physiologic weight bearing [4], [5], [6]. Computer models of the knee joint have also been generated; however, these have been validated based on available data from the limited studies, and assumptions of biologic function were made [7], [8]. It has also been shown that physiologic loading plays an important role in knee biomechanics, especially stability [9]. Recent studies have validated the accuracy of MR imaging for evaluation of joint position and cartilage contact [10]. Three-dimensional, non-invasive, in-vivo studies were, therefore, performed for evaluation of knee kinematics using high-resolution magnetic resonance imaging (MR) imaging of the knee joint in multiple weight bearing positions in a custom designed, physiologic weight bearing apparatus.

Methods: Ten patients (6 women, 4 men, average age 29 years old) with clinically normal knees were imaged in a 1.5 Tesla General Electric MR scanner at multiple positions of knee flexion. Their lower extremities were placed in a custom designed, MR compatible apparatus which simulated physiologic weight bearing in the form of axial loading. This was accomplished by allowing the patient to push down on a foot-plate with a constant resistance of 301bs. Sixty, 2-mm thick slices were obtained with S12X512, 0.23 mm pixels for each of the following positions: straight, partial flexion 1, partial flexion 2, partial flexion 3, and maximum flexion (Fig 1 shows a sample image). Images were transferred to a Spurc Ultra 5 workstation on which three-dimensional reconstructions were generated from the volumetric data using AnalyzR™ software. The images were then transformed to the same coordinate space by overlaying the tibia from each scan onto the tibia of the straight position scan. The femora were then transformed in a similar fashion with a resulting transformation matrix. This matrix was used to calculate the translations and rotations of the tibia relative to the femur. The motion parameters measured were varus-valgus, axial rotation, anterior-posterior translation, medial-lateral translation, and proximal-distal translation.

Tibio-femoral contact area of the medial and lateral compartments was measured by creating B-Spline lines on each sagittal image along the line of contact. The contact area was calculated by integrating the joint compression, and femoral roll-back with increasing flexion angle. Medial-lateral translation did not change significantly. Medial compartment femorotibial contact area averaged 380 mm² and decreased to 300 mm² with flexion while lateral compartment contact area remained relatively constant. Contact area centroids moved posteriorly both medially and laterally, and lateral compartment centroids moved slightly laterally with flexion.

Discussion: Results provide accurate three-dimensional motion information that correlates grossly with previous invasive and cadaver studies [1], [8], [11]. As expected, knee motion included tibial internal rotation, femoral roll- and slide back, joint compression, and valgus with flexion. These parameters have not previously been quantified in such non-invasive and three-dimensional fashion with weight bearing. The results thus verify many past studies and larger numbers of normal volunteers will provide more accurate quantitative results. This may prove helpful in design of joint replacement components.

Although decrease in femoro-tibial contact area with flexion was expected, the nearly equal posterior translation medially and laterally was unexpected. Previous studies have shown greater lateral posterior translation than medial [12], [4], and the lateral translation of the lateral compartment contact area had not been described. Our differences may be due to shape change related influence on the contact area centroid calculation; however, visual inspection of the contact area shapes did not show significant variation.

MR imaging, thus, provides excellent non-invasive evaluation of physiologic kinematics, and current study of both normal volunteers, and patients with pathology (anterior cruciate ligament deficiency, severe arthritis, etc.) will provide valuable information.

References: