INTRODUCTION: Forearm rotation is not a simple hinge-like motion, but a complex motion with rotational and translational components. It is thought these motions change with injury and disease and can be useful diagnostic indices. Several studies have assessed the forearm rotation axis and kinematics of the distal radioulnar joint (DRUJ) to static conditions, but in vivo dynamic forearm kinematics have not yet been reported in the literature. The purpose of this study was to analyze in vivo dynamic kinematics in normal forearms using fluoroscopy and 3D-2D registration methods to evaluate the forearm rotation axis and ulnar translation at the DRUJ.

METHODS: Five healthy male subjects (mean age 37, range 34-46) with ten forearms gave informed consent to participate in this IRB approved study. All subjects had normal forearm motion and had no history of disease or trauma to either upper extremity. Lateral fluoroscopic images of a forearm rotation activity were recorded at 15 Hz. Subjects rotated their forearms from maximum supination to maximum pronation with their elbow flexed to approximately 45° without any fixation of their upper limb. Subjects performed the activity in approximately 2 seconds per one cycle and three cycles were recorded. Subjects underwent CT scanning with a 1.0 mm slice pitch spanning the distal humerus to the proximal carpal row. Geometric bone models of the humerus, the radius and the ulna were reconstructed (ITK snap, Penn Image Computing and Science Laboratory, Philadelphia, PA), and anatomic coordinate systems were embedded in each bone model (Geomagic Studio, Geomagic, Research Triangle Park, NC). In brief, the humeral origin was placed at the midpoint of medial and lateral epicondyle, the Y-axis was parallel to the shaft, and Z-axis was a line connecting medial and lateral epicondyle. The radial origin was placed at the centroid of the proximal articular surface, Y-axis was parallel to the shaft, X-axis pointed anteriorly and Z-axis pointed distally. The ulnar origin was defined as the deepest point on the sagittal ridge, Y-axis was parallel to the shaft, X- and Z-axes pointed anteriorly and laterally, respectively. Three-dimensional forearm kinematics was determined using 3D-2D model registration techniques, including previously reported techniques (1) (Figure 1). The data were analyzed using custom programs (The MathWorks, Inc., Natrick, MA). Axial rotation angle of the radius relative to the ulna was determined using the ISB recommended rotation sequences, and volar/dorsal translation of the ulna was defined as the motion of the centroid of the distal ulnar articular surface relative to the centroid of the distal radial articular surface along the X-axis of the radius. The rotation axis of the forearm was calculated as a helical axis of radial motion relative to the ulna. One-way repeated-measure analysis of variance and post-hoc pair-wise comparison (Tukey) were performed for statistical analysis of kinematic data using Statview 5.0 (SAS Institute Inc., Cary, NC). The level of significance was set at P<0.05.

RESULTS: The arc of axial rotation of the radius was 157°±9°, with maximum supination of 77°±13° and maximum pronation of 80°±9°. The ulnar centroid was at 1.3±1.0mm volar relative to the radial centroid at maximum supination, and at 2.6±1.5mm dorsal at maximum pronation. Thus, the centroid of the ulna translated 3.9±1.5mm dorsally during rotation (Figure 2). There were significant differences in translation between 30° supination, neutral, 30° pronation, and 60° pronation by post-hoc pair-wise comparison. The rotation axis of the forearm passed through the centroid of the radial head and through the dorsal and radial portion of the ulnar head (Figure 3). The mean location of the axis for the DRUJ was 1.9±0.7mm dorsal and 0.5±0.9mm radial from center of the ulnar head. There was a significant dorsal shift as the forearm rotated from supination to pronation (p<0.025) (Figure 4).

DISCUSSION: We examined in vivo dynamic kinematics of normal forearms utilizing 3D-2D registration methods. Several studies previously have used static methods to analyze in vivo 3D kinematics of the forearm and DRUJ utilizing CT or MRI (2, 3). This is the first study to quantify 3D dynamic kinematics of the forearm. We showed that the ulnar head translated dorsally with pronation, and the rotation axis passed through dorsal portion of the ulnar head. These findings are mutually consistent since a dorsal center of rotation will result in the ulnar head translating dorsally during pronation. In fact, volar/dorsal translation values of the ulnar head relative to the centroid of the distal articular surface of the radius were quite close to the dorsal deviation of the rotation axis from the centroid of the ulnar head in each position. Most studies using static images showed that the rotation axis passed through the center of the ulnar head. Differences in muscle activities may explain the differences in location of the rotation axis between the present study and the previous studies. This dynamic method might be useful to objectively characterize normal forearm function. These results will provide the basis for future analysis of pathological forearm function, such as rotational contracture of forearm and DRUJ instability.