INTRODUCTION: The elbow has traditionally been described as a two degree-of-freedom joint (i.e. flexion-extension and pronation-supination) (1). While this may be true in the stable or intact joint, an unstable elbow may possess additional degrees-of-freedom, including significant joint translations. Posterolateral rotatory instability (PLRI) of the elbow, for example, is characterized by posterolateral translation of the radial head relative to the capitellum. Kinematic techniques currently available to quantify elbow motion, such as Euler angles and Screw Displacement Axes (SDAs), are not fully amenable of describing clinically-relevant joint translations, only rotations. However, Grood and Suntay (2) have described a Floating Axis analysis technique to quantify both translations and rotations in the knee. The purpose of this study was to apply this analysis technique to the elbow joint, and to verify its ability to quantify anterior-posterior radiohumeral translation in an unstable in-vitro model.

METHODS: Twelve fresh-frozen upper limbs (73±14 years), transected at the mid-humeral level, were tested. All soft tissue 10 cm proximal to the elbow joint was removed so that the specimens could be mounted in a vertical orientation using a humeral clamp. Each specimen was subjected to a pivot shift test (3), performed by the same clinician. This test is routinely performed to test for PLRI, and involves moving the arm through a passive range of flexion, while applying an axial force, supination torque, and valgus moment to the forearm. The resulting motion was recorded using an electromagnetic tracking device (Flock of Birds, Ascension Technology, Burlington, VT), with a receiver secured to the distal radius and the transmitter fixed with respect to the humerus. Testing was first conducted with all soft tissues intact, and repeated following transection of the lateral collateral ligament (LCL). At the completion of testing, several bony landmarks on the radius and humerus were digitized. These data were used to construct an Elbow Coordinate System (ECS) for the radiohumeral joint (Figure 1), to which the Floating Axis analysis could be applied. The ECS consists of three non-orthogonal axes: one fixed along the flexion-extension axis of the humerus ($e_0$), one fixed along the long axis of the radius ($e_1$), and their mutual perpendicular ($e_2 = e_0 \times e_1$). Translation reference points were selected on both the humerus (i.e. midpoint of the centers of the trochlea and capitellum) and the radius (i.e. centre of the radial head). Motion between these two reference points along the $e_1$ axis (i.e. the floating axis) represents anterior-posterior (A-P) radiohumeral translation, and was quantified throughout the arc of flexion for all motion trials. Data collected before and after ligament transection were analyzed using two-way repeated-measures ANOVAs and post-hoc Student-Newman-Keuls tests (α=0.05). In one specimen, the effect of relocating the translation reference points from the anatomic flexion axis (i.e. $e_0$) to the kinematic flexion axis (as determined from the mean SDA) was also investigated.

RESULTS: A typical A-P radiohumeral translation pathway recorded during the pivot shift test is shown in Figure 2. Average values for all twelve specimens at 20, 40, 60, 90, and 120° of flexion are shown in Figure 3. Statistical analysis indicated an overall effect of LCL sectioning ($p<0.001$), with the unstable joint experiencing significantly larger joint translations at all flexion angles ($p<0.05$). When the translation reference points were relocated onto the SDA, the absolute magnitudes of the translations changed (with the intact translations being minimized), but the relative differences between the intact and LCL deficient elbows remained the same.

DISCUSSION: Although only translational data is presented herein, the ECS and Floating Axis analysis allow both rotations and clinically-relevant translations of the radiohumeral joint to be quantified. The rotations that result from this analysis are the same as those obtained from an Euler ZYX Axes analysis, however the translations are easier to interpret since they correspond to clinical definitions of joint motion. The ability to quantify A-P radiohumeral translation is of particular interest in the study of PLRI. The increased translations observed with the LCL deficient elbows indicate the stabilizing influence of this ligament. This agrees with our previous work, which showed increased external ulnohumeral rotation with LCL sectioning (4). This is likely due to the intact annular ligament, which allows the radius and ulna to move as a unit, such that the radius translates posteriorly as the ulna rotates externally.

Little information regarding elbow joint translations has been previously published. Olsen et al. used a sliding potentiometer to directly measure A-P radial head translation, and observed a maximal posterior translation of 14.2mm at 90° of flexion during a pivot shift test following LCL sectioning (5). Our current results are similar (19.8mm). The magnitudes of the translations observed using the ECS are dependent upon the selection of translation reference points. Selecting points on the SDA generated from the intact motion will minimize the translations observed in the intact state. However, our results suggest that this is not necessary in a repeated-measures study, since the relative differences in translations are not affected by reference point selection. In summary, this analysis tool provides valuable information related to the changes in elbow motion pathways that should be useful in studies of joint stability and reconstruction techniques. The ability to describe both translations and rotations will lead to an improved understanding of elbow kinematics.