Introduction
Many attempts have been made to describe the flexion axis of the knee based on landmarks or simple geometric representations of the anatomy. An alternative approach is to use kinematic data to describe the axis of motion of the joint. The helical axis is one kinematic parameter that can accomplish this. The purpose of this study was to compare the correlation between kinematic axis of motion and anatomic axes.

Methods
Six cadaver lower extremities were skeletonized while preserving the knee joint capsule and quadriceps tendons. CT scans of the extremity were converted to CAD models that precisely related the bone surfaces to radio-opaque motion analysis markers. The limbs were mounted in a custom open-chain extremity rig that allows full range of knee motion [1]. Tibial motion was produced by a linear actuator attached to the quadriceps tendon in the direction of the vector addition of the absent quadriceps muscles. Three-dimensional kinematic data of the isometric extension motion of the knee were recorded at 30 Hz using a motion capture camera system and combined with CAD models of the extremity to evaluate joint kinematics through finite helical axis calculations [1].

Anatomic landmarks were placed on the CT derived CAD models of the extremities to define anatomic axes. Three landmark based axes were defined for comparison against the calculated helical axis; the epicondylar axis, the spherical axis, and the cylindrical axis. The femoral epicondylar axis was defined as a line connecting the peak of the lateral epicondyle to the sulcus of the medial epicondyle [2]. To define the spherical axis, one sphere was matched to the articulating surfaces of each of the posterior condyles, and a line was connected between the centers of those spheres. The cylindrical axis was defined as the central axis of two concentric cylinders oriented to surface match the same posterior condylar surfaces as the spheres [4]. The helical axis was calculated from the motion analysis data of the tibial rotation around the stationary femur in the open chain rig.

Data for the normal knee was processed by comparison of the helical axis to the landmark axes over varying ranges of flexion. The variation in helical axis direction within that range was also calculated.

Results
The flexion range with the minimum variation of anatomic parameters to the helical axis was 30-100°. Helical axis variation in this range was 5.5 ± 1.2, while the variation between the helical axis and those axes defined by TEA, cylindrical, and spherical landmark axes is shown in Table 1. A students t-test was performed on each data set with the null hypothesis that the angular difference between the anatomically defined axes and the helical axis is zero. All axes were found to be significantly different from the average helical axis in the range of 30-100° (P=0.013, 0.002, and 0.001, respectively). The tightest variation in the helical axis occurred at 40-50° of flexion 2.9 ± 0.7°. In the range of motion less than 30° of flexion, the helical axis variation is much larger due to a natural “screw home” tendency, and therefore is not evaluated in this study.

Discussion and Conclusion
None of the anatomic landmarks considered in this study represent a consistently valid approximation of the kinematic flexion axis of the knee. The TEA represents the closest approximation of the three with a 95% CI between 1.0 and 5.3°. The range of 30-100° represented the tightest variation over the largest range of flexion. Extension was defined at approximately 30° based on kinematic profiles of internal/external rotation which show a “screw-home” tendency beginning at 30° through extension. This behavior is consistent with an increase in helical axis variation in ranges that were less than 30° of flexion. In a previous open-chain model, both compartments of the joint were spinning around 45 degrees of flexion, which is consistent with the smallest helical axis variation observed in the 40-50° range.

References