INTRODUCTION
Irregular motion in the C1 and C2 vertebrae can lead to headaches, C2 dens fracture, artery compression, nerve root compression, and spinal cord compression. The kinematics of these two vertebrae are only well-defined in flexion and extension, but not in twisting.

Attempts have been made to quantify C1 and C2 rotation, but these studies were either limited to in vitro motion or in vivo motion in static, supine positions. These types of studies are not representative of full range, physiological motion because they do not account for gravitational and muscle forces in live and upright subjects.

The Orthopaedic Biodynamics lab attempted to quantify motion of the entire cervical spine in the Synthes study funded by Synthes Spine. Data was collected from twenty-nine young, healthy subjects. This project is a subset from the Synthes data set, using only the twist trials from eighteen of the twenty-nine subjects where C1 and C2 were visible.

OBJECTIVE
I will accurately model C1 C2 rotation with computational software to describe full range, physiological motion in young and healthy people.

HYPOTHESIS/SUCCESS CRITERIA
We will demonstrate the ability to accurately measure upright, dynamic C1 and C2 motion during head rotation in vivo. CT models will be matched to x-ray images will be considered accurate within 0.5 degrees between frames of x-ray data.

METHODS
Subjects were seated upright in a biplane x-ray system and instructed to twist their head through their full range of motion to the beat of a metronome while dynamic x-ray images were captured. An eight camera Vicon system tracked reflective markers placed on the outside of the body through the motion trial. CT scans were obtained from each participant.

The C1 through C7 vertebrae were segmented from the CT images (Materialise Mimics). Next, anatomical markers were interactively placed on each vertebra to define a coordinate system. Then, the bone models were matched to the biplane x-ray images frame-by-frame after those images were corrected for distortion using custom lab software. This tracking method has been validated for 0.33 mm in intervertebral translations and 1.11° for intervertebral rotations [1]. Finally, the bone models and the coordinates are loaded into custom software to create virtual 3D models for each subject.

Each twist trial was normalized at every time point by a static trial and and the Vicon data was used to track total head relative to body motion during the trial. The intervertebral rotations and translations on each anatomical axis were plotted versus total head rotation.

RESULTS
The maximum head relative to body rotation to one side was 72.5±7.5°. C1-C2 rotation relative to total head rotation was linear in the midrange and became linear after approximately 30°. As C1 rotated, it underwent extension in the sagittal plane and lateral bending toward the contralateral side. C1- C2 rotation accounts for half of total head rotation on average.

DISCUSSION
We demonstrated the ability to accurately measure upright dynamic C1 and C2 motion during head rotation in vivo. The values reported for total head rotation are similar to cadaver and supine subjects [2,3,4]. Nonlinear C1 motion is also consistent with supine subjects [4]. The bending we observed is significantly smaller than in vitro and supine studies, but this can be attributed to the supine subjects not being subject to gravitational forces [4].

C1 and C2 can be obstructed by the mandible and skull when the subject faces the x-ray machine directly so only eighteen of the twenty-nine subjects had visible C1 and C2 vertebrae. In similar studies, subject position inside the biplane system will be changed.

Quantifying C1 and C2 rotation has promising applications in diagnosing ligament damage, especially in whiplash and concussion patients. Currently, static imaging is very limited in identifying intervertebral ligament damage because of their small size, but kinematic changes may be easier to identify.

ACKNOWLEDGMENTS
This project was funded by Synthes Spine. My mentor is Dr. William Anderst and Dr. Bryan Rynearson is submitting a manuscript on this study. Undergraduates Jessica Sider and Zachary Adgate also assisted on this project.

REFERENCES