INTRODUCTION

The cervical spine allows humans to perform complex motions including lateral bending, twisting, and flexion/extension. The anatomical structures of the cervical spine, such as the cervical discs, facet joints, and ligaments, are constantly under stress due to everyday activities. Sustained stress over time causes injury and degeneration in the structures of the cervical spine and the development of degenerative cervical spine disease.

Degenerative cervical spine disease occurs in about two-thirds of the United States population during the course of their lifetime and is the result of work, sports, aging, stress, or trauma. Anterior cervical disectomy and fusion (ACDF) is the most common surgical procedure to treat degenerative cervical spine disease in the United States. This procedure is performed approximately 150,000 times per year and involves fusing adjacent vertebrae, referred to as a motion segment, together. Twenty-five percent of people who undergo ACDF surgery require an additional revision surgery within ten years of the initial operation. The requirement for an additional surgery is thought to be the result of Adjacent Segment Disease (ASD), which is the degeneration of the bone segments adjacent to the fused vertebrae. ASD may be a result of the natural degeneration in the cervical spine or it may be caused by increased strain in the cervical segments adjacent to the fused bones.

Spinal implants, another treatment for cervical disc injury, is not as common as ACDF because current implants do not offer a full range of movement. In order to improve the effectiveness of spinal implants, the natural motion of the spine must first be defined. With more effective spinal implants, treatment for degenerative cervical spine disease will improve and the quality of life of patients will significantly increase.

OBJECTIVE

The objective of this study is to analyze flexion/extension, twist, and bend motions of the cervical spine in young, healthy patients in order to provide substantial data on the movement between vertebrae in the cervical spine. For this particular study, only the dynamic twist data will be presented.

With the data obtained through this study, spinal implants can be developed to be specific to each motion segment and improved to better mimic the natural motion of the spine, thereby improving the spinal implant operation.

HYPOTHESIS/SUCCESS CRITERIA

For every patient, 3 dynamic trials (twist, bend, flexion/extension) must be analyzed in addition to static trials. Kinematic data will be obtained from at least 30 young and healthy patients, ranging from 20 to 30 years old, in order to have enough trials to establish statistical significance.

This is a baseline study for modeling twisting and bending motions, and the data obtained will be compared to future studies on fusion and spinal implant patients.

METHOD

Four stages were completed during the course of the study for each patient: X-Ray imaging, segmentation, model based tracking and kinematic analysis.

First, patients were placed in a bi-plane x-ray system. This system allows 3-D analysis and provides dynamic x-ray images that were used to accurately model the spine through full motion. The x-ray system created images of the cervical spine on two different planes, which allowed for the tracking of 3-D bone models. The patients were asked to perform a twisting motion and were imaged at 30 frames per second over 3.2 seconds.

During segmentation, CT images of the cervical spine of each patient were collected. The CT scans were resliced, which created three times the number of original images using interpolation between images. Reslicing allowed for more accurate segmentation. Vertebrae were separated from the CT scans using thresholding techniques that allowed the separation of bone tissue from background soft tissue based on the density of the tissue. After thresholding, patient-specific bone models of each individual vertebra from the bone segments C3 to T1 were created. The bone models were then used in model-based tracking.

During model based tracking, a coordinate system was established on each vertebra that was used to measure relative motion between adjacent bones. Using the patient-specific bone models created from the CT scan and dynamic biplane radiograph images that were collected while the patient performed head rotation, the individual vertebra were tracked for the entire range of motion.

Once the 6 cervical vertebra models were completely tracked and prepared with a coordinate axis, the bone models and model based tracking data were combined for kinematic analysis. A 3-D model of the cervical spine was created and the quality of tracking was observed. After ensuring that adjacent bones did not touch and that all models moved smoothly, kinematic data was measured. The translations and rotations that occurred between vertebrae were calculated over the entire dynamic movement. The overall range of motion of each motion segment, including degrees of pure lateral bending, axial rotation, and flexion/extension, was calculated.

When all 30 patients are completely tracked and analyzed, two-tailed p tests will be performed to test the difference in the range of motion between motion segments.
RESULTS
The data shown in Figure 1 shows the range of motion (ROM) of pure bend, axial rotation, and flexion/extension for each motion segment during a twisting motion from 11 patients. The error bars are included, but since 30 patients have not yet been analyzed, statistical significance cannot be concluded.

The C3/C4 and C4/C5 motion segment showed the largest range of pure twisting motion at 10.92 ± 3.15 degrees and 10.69 ± 2.41 degrees respectively. The range of axial rotation decreased in the inferior direction, with the range of motion in the C7/T1 motion segment exhibiting 3.51 ± 1.40 degrees. The degrees of pure bend in the twisting trial were actually greater than pure rotation in all motion segments except C4/C5. Motion segment C6/C7 had 5.44 degrees greater bend than rotation. The flexion/extension data showed that flexion/extension range of motion was the lowest of the three pure motions in all motion segments except for C7/T1. The range of flexion/extension generally decreased inferiorly, but increased in the C7/T1 segment.

DISCUSSION
The study is ongoing and additional patients must be analyzed in order to achieve statistical significance in the results. Based on the data obtained so far, the coupled twisting motion (combination of lateral bending, axial rotation, and flexion/extension exhibited in the results) presents new joint kinetic data that was not previously known from past research on cervical spine kinematics. We hypothesize that the degrees of bend was equal to or greater than the degrees of rotation because of the anatomy of the facet joint. When humans perform the twisting motion, the movement begins with pure axial rotation. After just a few degrees of motion, adjacent facets (inferior facet of superior vertebra and superior facet of inferior vertebra) contact each other, forcing the patients to perform a bending motion in order to continue the twisting movement. The C6/C7 motion segment had a very large difference between pure bend and pure rotation in comparison to the other motion segments. This may be due to the facet joint of C6/C7, which is at a larger angle from the axial plane than the other motion segments. Since the facet joint is at a larger angle, the patient is forced to bend more to complete a full twisting movement. We hypothesize that at a facet joint angle of 45 degrees, the range of motion of the pure bend and pure twist during the twisting motion will be equal. This was observed in the C4/C5 joint, and we found that the angle of the facet joint for the C4/C5 motion segment is closest to 45 degrees in comparison to the other motion segments. This phenomenon, which further describes the complexity of the twisting motion, may provide important insight on why ASD occurs and why current implants are not effective at restoring full range of motion in the cervical spine.

A limitation of the study was the repeatability of the twisting motion among separate patients. Patients were told to perform a twisting motion and a research scientist demonstrated an example of the movement, but constraints were not used to guide the patient through the movement.

CONCLUSION
Since the study is not yet complete, distinct conclusions cannot be made. Once the target number of analyzed patients is reached, we hope to define the normal movement of the cervical spine and therefore set a benchmark for future studies on the spine. This may include developing more effective spinal implants, improving the fusion operation, calculating the change in kinematics of the cervical spine over increased age, and measuring the change in kinematics of the spine with loading conditions. Additionally, in the future we would like to compare the kinematics of patients who receive the implant operation to patients who receive ACDF and attempt to improve the quality of life of patients who receive such operations.

ACKNOWLEDGMENTS
I would like to thank Dr. Tashman and William Andorf for assisting me with my project. I would also like to thank Dr. Woo and Jonquil Flowers for assisting me in refining my presentation and abstract.

REFERENCES