INTRODUCTION
Degenerative disc disease (DDD) of the cervical spine is a common condition that causes significant pain, disability, and medical expense. For example, treatment for DDD in 2000 exceeded 110,000 patients in the United States alone [1]. A common treatment for patients involves removal of the degenerated disc and fusion of the adjacent vertebral bodies. However, previous research has shown that as many as 25-92% of patients treated with fusion have disc degeneration at the adjacent levels within 10 years after surgery [2,3]. It has been hypothesized that this degeneration result from changes in motion at vertebral segments adjacent to the fusion site [4]. However, it is unknown if fusion patients have altered cervical spine motion. Thus, the objective of this study was to compare the dynamic, three-dimensional (3D) motion of the cervical spine in control subjects and cervical fusion patients.

MATERIALS AND METHODS
Testing Procedures: Following IRB approval, ten subjects were tested. Five subjects had no history of spine pathology or spine surgery (control subjects, mean age: 28±1.6 years) and five subjects had surgical fusion of the C5-C6 vertebrae (fused subjects, mean age: 49±5.1 years). The fused subjects were tested at a mean of 21 months post-surgery. Subjects were seated with their neck centered in a biplane x-ray system [5]. Biplane x-ray images were acquired at 60 Hz during two motion tasks: axial neck rotation and neck extension. For the axial neck rotation task, subjects rotated their neck from a position of maximal right rotation to maximal left rotation. For the neck extension task, subjects moved their neck from a position of full flexion (chin against chest) to full extension. 3D motion of the head relative to the torso was also recorded using a video-based motion capture system. Following testing, CT scans of the cervical spine were acquired.

Data Analysis: Motion at C4-C5 and C6-C7 was measured for each subject, as these represented the vertebral motion segments above (C4-C5) and below (C6-C7) the fusion site for the fused subjects. To accomplish this, CT images of the vertebral bodies (C4-C7) were segmented from the surrounding soft tissues and reconstructed into 3D bone models. The 3D position and orientation of each vertebra was determined from the biplane x-ray images using a model-based tracking technique [6]. Briefly, this technique generates a pair of digitally reconstructed radiographs (DRRs) from the 3D bone model, and then optimizes the correlation between the DRRs and the corresponding biplane x-ray images. This technique has been previously validated and is accurate to within ±0.6mm.

Using custom software, anatomic coordinate systems were created for each vertebra (Figure 1). Lateral bending was defined as rotation about the X-axis (directed in the anterior direction), flexion-extension was defined as rotation about the Y-axis (directed to the patient’s left), and axial rotation was defined as rotation about the Z-axis (directed in the superior direction). Kinematic outcome measures were determined by calculating translations and rotations at the adjacent vertebral segments (C4-C5 and C6-C7) for each group [7]. For axial neck rotation, C4-C5 and C6-C7 total range of motion was calculated from 60° right rotation to 60° left rotation. For neck extension, C4-C5 and C6-C7 range of motion was calculated from 50° neck flexion to 50° neck extension.

Statistical Analysis: For each motion task (axial neck rotation and neck extension), a t-test compared control and fused subjects in terms of the total range of motion about each anatomical axis above (C4-C5) and below (C6-C7) the fused segment. Significance was set at p<0.05.

RESULTS
For the axial neck rotation motion task, rotation was evident about all three anatomical axes although the prominent rotation was in lateral bending. Rotation at C4-C5 and C6-C7 was greater in the fused subjects about all three anatomical axes, but this finding was statistically significant for only lateral bending (p=0.04, Figure 2).

For the neck extension task, flexion-extension was the dominant motion, with significant rotations in lateral bending and axial rotation. The data failed to detect any statistically significant differences between the control and fused subjects at each motion segment. This was consistent for rotations about all 3 anatomical axes (p>0.12, Figure 3).

DISCUSSION
This study demonstrated differences in C4-C5 and C6-C7 motion between control subjects and patients who had undergone fusion of the C5-C6 vertebrae. In general, the fused subjects demonstrated greater range of motion about all anatomical axes than the control subjects for both axial neck rotation and neck extension motion tasks. However, the exception to this finding occurred during the neck extension motion task, where fused subjects demonstrated lower range of motion in flexion-extension than the control subjects. The significance of this finding is unclear, but on-going research will test additional subjects to more fully characterize kinematic differences following cervical spine fusion.

Cervical spine motion is complex, and a 3D dynamic in-vivo measurement technique is necessary to accurately quantify the rotations that occur about all three anatomical axes. An accurate measurement of adjacent segment motion following spinal fusion is an important step toward understanding the relationship between spinal fusion and adjacent level disc degeneration.

REFERENCES