INTRODUCTION
Theoretically, a fusion will lead to increase stresses and strains at the levels above and below that fusion. And the concern is that these increased stresses actually may lead to accelerated degeneration or wearing out at the levels above or below that fusion and subsequent osteophyte formation in the segments adjacent to the fusion. The problem is trying to differentiate that acceleration from the natural history of disc degeneration. There is a suggestion that spinal fusion may cause accelerated breakdown at the adjacent spinal levels, although at this point in time, this has not been proven. The focus of this research is to examine the resulting stresses in the nucleus and annulus of the disc and the endplates of the vertebrae of the entire cervical spine following single and double-level fusion at different cervical levels. Our findings show that fusion leads to disc degeneration, which promotes high stresses at the vertebrae endplates, and therefore leads to osteophyte, or bone spur, formation.

METHODS
A previously validated finite element model was used to create the models of the cervical spine used in our study. In order to study the case of single fusion, the cervical spine from C3 to C7 was examined while fusing two of the vertebrae in four separate scenarios (C3-C4, C4-C5, C5-C6, and C6-C7). A similar setup was used for the case of double fusion, with separate fusions done at C3-C4-C5, C4-C5-C6 and C5-C6-C7. The fusion procedure simulated was a modified Smith-Robinson grafting technique, which involves removal of the intervertebral disc at the fusion level, preceded by resection of the anterior and posterior longitudinal ligaments. Each model was analyzed in the case of flexion, extension, lateral bending, and axial torsion for physiological loads. The overall stress on the intervertebral discs and endplates of the vertebrae (O1), lower fused vertebra (O2), and levels inferior (I) to fusion were examined following the fusion procedure. The increased stress results in an accelerated rate of degeneration of the disc. Decreased height and volume of the disc leads to increased stress and pressure on the endplates of the vertebrae. The bone responds to the increased stress by strengthening itself and forming osteophytes, or bone spurs, which can be very painful to the patient and require treatment. This effect is compounded on the increased endplate stresses seen following fusion. For example, during flexion, an increase in stress in the endplate of 62.7% is seen in the upper endplates of the levels inferior to fusion (Figure 2). Our results also show that the lower disc adjacent to the fusion tends to suffer more stress than the upper disc due to increased rotation. Again in the case of flexion, there is 22.4% higher nucleus stress increase in the lower levels versus the higher levels in single fusion and a 43.1% higher nucleus stress increase in the lower levels in double fusion. This finding is directly related to the greater number of reported problems in the inferior level of fusion patients. These maximum stress levels are found to be larger for double fusion than for single fusion.

RESULTS
The overall stress on the intervertebral discs and endplates of the adjacent levels of the cervical spine is increased following a cervical fusion, as compared to the normal spine (Figures 2 and 3). For example, during flexion, an increase in stress in the nucleus of 80.3% is seen in double fusion and an increase of 62.7% in single fusion (Figure 3). These findings are vital to providing evidence of further pathology following the fusion procedure. The increased stress results in an accelerated rate of degeneration of the disc. Decreased height and volume of the disc leads to increased stress and pressure on the endplates of the vertebrae. The bone responds to the increased stress by strengthening itself and forming osteophytes, or bone spurs, which can be very painful to the patient and require treatment. This effect is compounded on the increased endplate stresses seen following fusion. For example, during flexion, an increase in stress in the endplate of 62.7% is seen in the upper endplates of the levels inferior to fusion (Figure 2). Our results also show that the lower disc adjacent to the fusion tends to suffer more stress than the upper disc due to increased rotation. Again in the case of flexion, there is 22.4% higher nucleus stress increase in the lower levels versus the higher levels in single fusion and a 43.1% higher nucleus stress increase in the lower levels in double fusion. This finding is directly related to the greater number of reported problems in the inferior level of fusion patients. These maximum stress levels are found to be larger for double fusion than for single fusion.

Figure 1 Finite element model of the cervical spine from C3 to C7, indicating single and double level fusion.

Figure 2 Graphs of upper and lower endplate average stress change for single fusion during flexion, extension, lateral bending and axial torsion. Includes values for levels superior (S), upper fused vertebrae (O1), lower fused vertebrae (O2), and levels inferior (I).

DISCUSSION
Based on our study, cervical fusion will lead to faster disc degeneration and eventual formation of osteophytes. The drastically increased stress observed in the intervertebral discs of the fused model when compared to the normal model of the cervical spine, are evidence of this relationship. This information can prove to be very valuable to the clinician when treating fusion patients at follow-up. It will allow the clinician to assess further disc degeneration with concrete biomechanical evidence. Once again, however, one should not have a cervical fusion unless it is considered necessary. At that point, the risk of degeneration at adjacent segment levels may be worth taking.

Figure 3 Graphs of annulus stress change and nucleus stress change for single and double cervical fusion during flexion, extension, lateral bending and axial torsion averaged for levels superior (S) and inferior (I) to fusion.