INTRODUCTION:
Cervical spine disorders can contribute to a number of ailments including neck pain, radiculopathy, and myelopathy among others. There have been few studies examining the dynamic response of the cervical intervertebral disc (IVD) axial compression. There is a paucity of information describing the dynamic response of cervical IVD to axial loading. Most studies have focused on exploring the mechanical properties of the IVD in order to assess IVD behavior. Most spine studies examined the deformation response of lumbar IVD in compression, which include axial deformation and bulge. The goal of this study was to examine the amount of anterior IVD displacement and axial deformation in the cervical discs subjected to axial loading. This study allowed us to examine the material properties of the cervical disc with a focus on plastic deformation.

METHODS:
Three intact cervical spine specimens were sectioned into three C3-C4 Functional Spinal Units (FSUs) and two C5-C6 FSUs. The IVD were left intact. The specimens were prepared so that a smooth level surface was created allowing for symmetric load distribution. The posterior elements and associated ligaments remained on the specimen to mimic physiological conditions. The specimens were thawed and were placed, unconstrained, into an Instron mechanical testing machine. A preload of 50 N was applied before testing to ensure full contact and to minimize slippage of the specimen. Each specimen was compressed in the machine for 3 cycles for each maximum load. The maximum load increased from 100 N to 550 N in steps of 50 N. The change in vertical deformation was measured using the values provided by the Instron machine. The bulge was then measured using Linear Variable Differential Transformers (LVDTs). LVDTs were placed to measure the relative displacement of the disc to the bone (figure 1). The anterior bulge was measured because the posterior elements were included to obtain realistic results. The IVD bulge was then calculated, taking into account the change in position of the disc relative to the change in position of the bone in the loaded and unloaded conditions. The anterior bulge values and vertical deformation values were then processed to reduce the noise, plotted and analyzed. In order to validate this method, a lumbar specimen was prepared and tested in the same manner as the cervical discs. The results were then compared to literature on lumbar IVDs and the values were found to be similar. The FSUs were then dissected for gross analysis of the IVD.

RESULTS:
Five Cervical specimens with the posterior elements intact: three C3-C4 FSUs and two C5-C6 FSUs were tested in the manner stated above. Anterior IVD bulging increased until it reached a maximum at a load of 350 N. In one specimen the load peaked at 450 N. Once the peak was achieved, the anterior deformation plateaued; however, the axial deformation continued to increase (figure 4 and 5). The slope of the initial anterior displacement occurs in the range of 1900N/mm to 4100 N/mm with the mean being 2724 N/mm. The slope of the axial deformation occurs in the range of 950 N/mm to 1300 N/mm with a mean of 1130 N/mm (figure 6). On gross examination there was no IVD herniation and the endplates remained intact (figure 3).

DISCUSSION:
It is shown that the anterior bulge is limited to about 0.1 mm for a certain loading range while the axial (vertical) deformation increases, then it continues to increase, thus a stiffening of the disc may occur. Furthermore, the role of the uncovertebral joints cannot be underestimated as these joints prevent any lateral IVD displacement and may limit disc height reduction by contacting the cephalad vertebral body. In contrast, the lumbar spine demonstrates a different deformation pattern where both vertical deformation and bulging increase linearly until failure. There are many differences between the lumbar spine and the cervical spine including size, articular facet orientation, presence of uncovertebral joints, and vertebral body shape. Reported data tested the specimens with the posterior elements removed. Both anterior and posterior IVD displacement needs to assess in the presence of posterior elements. Future testing should take IVD degeneration and bone mineral density into account.

SIGNIFICANCE:
This study demonstrates that cervical IVD and FSU behave differently from the lumbar FSU. By studying IVD displacement as a function of load the amount of physiologic and pathologic cervical loading can be determined. The intriguing discovery seems to indicate that IVD bulging stops after certain load limit is reached. If unloaded prior to the 700 N load is reached, the disc bulge retracts completely. More experiments are planned to assess this unique behavior not seen in the lumbar spine. Studying the effects of cervical loading coupled motion will lead to a better understanding of cervical biomechanics and implant design.