INTRODUCTION:
Cervical spondylotic myelopathy is the most common spinal cord disorder in persons more than 55 years of age in North America and perhaps in the world [7]. It is a chronic degenerative condition of the cervical spine that results in the reduction of spinal canal diameter and thereby compresses the spinal cord and the associated nerve roots [1].

Surgical options can be broadly classified into two categories namely, anterior and posterior approaches. This study focuses on posterior based approach (i.e. laminectomy or laminoplasty) which is considered when multiple levels of the spine have to be decompressed or when most of the cord compression results from posterior pathological conditions. Historically, laminectomy has been regarded as the standard treatment for multi-level cervical spondylosis and myeloradiculopathy. However, the results of the procedure were universally unsuccessful with complications such as segmental instability and postoperative kyphosis [6]. Because of such concerns, laminoplasty was developed as an alternative to laminectomy. It is mainly intended to relieve pressure on the spinal cord while maintaining the stabilizing effects of the posterior elements of the vertebrae. Different laminoplasty techniques have been described which vary by where the hinge and opening of the lamina are developed. They can be broadly classified into two types namely open door (ODL) and double door laminoplasty (DDL).

METHODS:
In this study, a detailed validated subject-specific 3D finite element model of the cervical spine (C2-T1) was used [4,9]. The previous intact model was updated to 2Nm and was modified to simulate the surgical procedures of laminectomy and laminoplasty at levels C3-C6.

Simulation of Laminectomy: The lamina, spinous process and the associated ligaments (interspinous ligaments, ligamentum flavum) were removed. Facet joints were kept intact.

Simulation of ODL: A bicortical cut was simulated along the junction of the lamina and the lateral mass of the intact vertebral mesh by completely removing a layer of elements. On the contralateral side, a hinge of approximately 3-4mm was created along the junction of the lamina and lateral mass by removing elements representing the unicortical layer. The spinous processes of the involved vertebrae (C3-C6) along with the interspinous ligaments were resected. Additionally, the ligamentum flavum at the unaltered levels (C2-C3 and C6-C7) was also cut partially on the open side of the lamina to allow laminar opening. Two screw holes in the lateral mass and one hole in the lamina were created based on the desired plate position. Care was taken to angle the screws away from the facet joints. The lamina of each vertebrae, C3-C6, was opened towards the hinge by applying a uniform load. The stresses developed in the vertebra while opening the lamina tend to close it back and hence have to be stabilized using plates and screws. The titanium plate and screws were meshed with hexahedral elements using IA-FEMesh [2] and were assigned an elastic modulus of 116GPa and Poisson’s ratio of 0.3. Small sliding contact was formulated at the interface between the bone and the laminoplasty constructs. Additionally, the surfaces of the bone/screw and the screw/plate were tied during the analysis.

Simulation of DDL: Two bilateral hinges at the junction of lateral mass and lamina were created by removing the elements corresponding to the unicortical layer. The spinous process was sagittally split until a laminar opening of 10mm was obtained. The technique also involves resection of interspinous ligaments at all the involved levels and partial removal of the ligamentum flavum at the midline from C2 to C7 to allow for laminar opening. A 10mm trapezoidal shaped hydroxyapatite (HA) spacer was meshed with
hexahedral elements. The bony union observed in many clinical studies between the HA spacers and spinous process was simulated by using the TIED command in ABAQUS [3].

Figure 1 shows the simulated laminoplasty models. All three surgically simulated models (namely ODL, DDL and laminectomy) were tested using a pure moment of 2Nm under physiologic flexion/extension (±MX), right/left lateral bending (±MZ), and right/left axial rotation (±MY) modes. The inferior nodes of the T1 vertebra were fixed in all directions and a moment of 2Nm was applied on the superior surface of C2. The analysis was performed using the finite element software ABAQUS 6.9. Ranges of motion, stresses in the annular regions of the intervertebral disc and cortical regions of the vertebral bodies were analyzed and compared to that of the intact model. Stresses in the laminoplasty constructs (screws, plate and spacer) were evaluated for their stability.

Figure 1: Open Door Laminoplasty(Left); Double Door Laminoplasty(Right)

RESULTS:
During all the six loading modes, the von Mises stresses in the plate, screw, and spacer were within the yield strength of the implant and spacer respectively.

Figure 2: Percent changes in C2-T1 range of motion after ODL, DDL and laminectomy

Figure 2 compares the percent changes in the range of motion after laminoplasty and laminectomy. The surgical procedures had significant effect in flexion while minimal changes were observed in the other loading modes. ODL resulted in a 5.4% increase in C2-T1 range of motion during flexion, while less than a 5% change was observed in the other loading modes. DDL resulted in a significant 20% increase in the overall range of motion during flexion with marginal changes in other loading modes. Laminectomy resulted in a substantial 57.5% increase in the total range of motion during flexion only with minimal changes in other directions.

After ODL, there was a 39% and 20% increase in the motion at C2-C3 and C6-C7, while no substantial changes were observed at the altered levels. The percent increase in the motion after DDL varied from 4.3% to 34.6%. Laminectomy at C3-C6 led to significant increase in motion across all the levels from C2-C3 to C6-C7.

A significant increase in the cortical stresses of the vertebral bodies was observed at levels C3-C6 after the surgical procedures, with the posterior regions demonstrating higher stresses than the anterior regions. DDL recorded higher stresses than ODL. This could be due to the increased stresses developed in the vertebrae with opening both the lamina as opposed to the single lamina in ODL. Figure 3 shows the percent changes in the annular stresses of the intervertebral discs after the simulated surgical procedures during flexion. Significant changes were observed during flexion and correlated to the changes in the intersegmental rotation where unaltered levels were affected after ODL and altered levels showed substantial increases after DDL and laminectomy.

Figure 3: Percent changes in the annular stresses during flexion

DISCUSSION:
Numerous clinical studies have addressed the influence of multi-level laminoplasty on the kinematics of spine. To our knowledge, currently there exists no other computational study that compares the biomechanical effects of the two laminoplasty techniques. The preservation of range of motion after ODL was observed in other in vitro studies [8]. Kubo et al. [5] showed an inclination towards increased motion at all the levels after DDL which explains the role of lamina-ligamentum flavum complex in the stability of spine. The instability after laminectomy was observed only during flexion as no facet injury was simulated in the current study. The significant increase in the cortical stresses of the vertebral body after both the laminoplasty and laminectomy procedures may be clinically correlated to the degenerative process. To further augment/validate the finite element studies, we are currently performing flexibility tests on cadaveric cervical specimens after laminoplasty and laminectomy.

REFERENCES: