Cervical spine degeneration is caused by the intervertebral discs wearing down. This can cause pain, stiffness, and eventually, cervical stenosis, causing compression of the spinal cord and the nerves.\(^1\)

Currently, spinal fusion is the one of the main surgical technique to treat cervical spine degeneration. Spinal fusion accounts for 3.1% of all surgical operations.\(^2\) The treatment helps to alleviate the pain and discomfort caused by the degenerated cervical vertebrae by immobilizing the damaged vertebrae. The process involves placing a bone graft between two or more vertebrae and securing it with either screws or wire.

In vitro biomechanical testing is important in determining precise surgical techniques. Traditional testing methodologies are designed for comparative testing and have little input from in vivo data. Two separate studies have attempted to make in vitro biomechanical testing more accurately represent physiologic data by applying different loading conditions other than an unconstrained pure moment, which is the current gold standard.\(^3\)\(^4\) The study by Miura focused on the analysis of a pure moment, while the study by Diangelo focused on applying a compressive loading to the cervical spine. A study in 2013 by Bell expanded the standard pure moment loading by combining it with axial loading and follower loading.\(^5\)

My study focuses on the same loading conditions, but applying them to a 3D virtual cervical spine model and the resulting kinematics. Once the model is completed, the results can be compared to the in vitro kinematic data acquired by Bell.

**Objective**

The objective of my study is to determine how different loading conditions change the kinematics of the virtual cervical spine model.

**Hypothesis**

My hypothesis is that a combined loading of pure moment, axial loading, and follower loading will best replicate in vivo kinematic data accurately.

**MATERIALS AND METHODS**

CT scans of fresh-frozen human cervical cadaveric specimens were created and segmented in Mimics (Materialise, Leuven) and masks were created of each of the vertebrae. These masks were then smooth and reconstructed into 3D models. The models were then exported in STL format and imported into Simulink (Mathworks Inc. MA).

The properties of the ligaments were implemented in the model using a study in 2009 by Dr. Hartman.\(^6\) Hartman’s study collected data on the range of motion (ROM) when 2.5Nm of torque was applied while different ligaments were cut. I calculated the different ligament stiffnesses and joint stiffness by using the resulting ROM of the total cut joint system. I compared that ROM to the ROM of the joint system with single ligaments and calculated the stiffness of the ligaments until the whole joint system was recreated.

A spherical joint was used to model the intervertebral disc with a different stiffness for each degree of freedom, allowing for pitch, roll, and yaw. A flexion moment of 2.5Nm was applied to the model at the center and the resulting ROM (in degrees) was recorded. As seen in Figure 1, the attachment points for each of the ligaments is visualized with a tiny sphere. Secondly a 100 N axially compressive load was applied to the top vertebrae down through the center of rotation and the simulation was ran a second time.

**RESULTS**

The ROM of the model for each joint system was between 10.5 degrees and 12.5 degrees when only the pure moment was applied to the model. Applying the vertical compressive loading at the joint of the C3-C4 vertebrae increased the ROM of for every joint system. The more inferior the joint system is, the larger the increase in the ROM.
DISCUSSION
The resulting ROM of each joint system are within the expected ranges. The application of the pure moment matches the results of the Miura study. Both sets of data are within one to two degrees of each other. This matches our hypothesis that applying a single pure moment across the model with have near-equal magnitudes for the ROM as compared to in vivo studies, but also results in equal segmental rotation for each joint segment.

The results of the compressive loading do not perfectly match the study completed by DiAngelo. The DiAngelo study applied an eccentric single compressive load, while this study applied both a pure moment and compressive load. The application of the compressive load altered the model so that it was no longer experiencing a pure moment. The trend in the DiAngelo study was that the middle segments flexed further than the outer segments, while the lower segments in the simulation flexed further. A possibility for the difference of results is abnormalities of the spine used in my model. This study only used n=1 specimens and analysis of the cervical spine used to create the virtual model shows that it may have an abnormal alignment of its vertebrae, affecting the results of data when the compressive loading is applied. Future work will consider additional specimen with different anatomy and additional loading conditions.

CONCLUSION
With further development of the model, it can be used to study the effect of different compressive loading methods that best replicate in vivo loading. Possible future direction is to make the model comparable to in vivo kinematics, allowing more in-depth studies of the different medical procedures that help to reduce cervical spine degeneration such as cervical spine fusion.

Overall, the model will help to understand the forces acting on the human cervical spine, which will lead to better medical devices and procedures.

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