Design and Implementation of Anatomically and Physiologically Accurate Spinal Disc Teaching Models

USC Viterbi School of Engineering
Alfred E. Mann Department of Biomedical Engineering

Nicholas Dorgan[1], Arjun Karnwal[1], Anson Li[1], Joseph M. Derian[2]
[1]Viterbi School of Engineering, University of Southern California, CA
[2]Division of Biokinesiology and Physical Therapy, University of Southern California, CA

Introduction

Traditional physical therapy classes involve analysis of mobility of key joints (knee, arm, shoulder, etc), which can be performed using human subjects. Analysis of mobility of subcutaneous structures (spinal discs) is less feasible, prompting development of custom anatomically accurate, physiologically consistent models to allow for exhaustive understanding of spinal cord mobility.

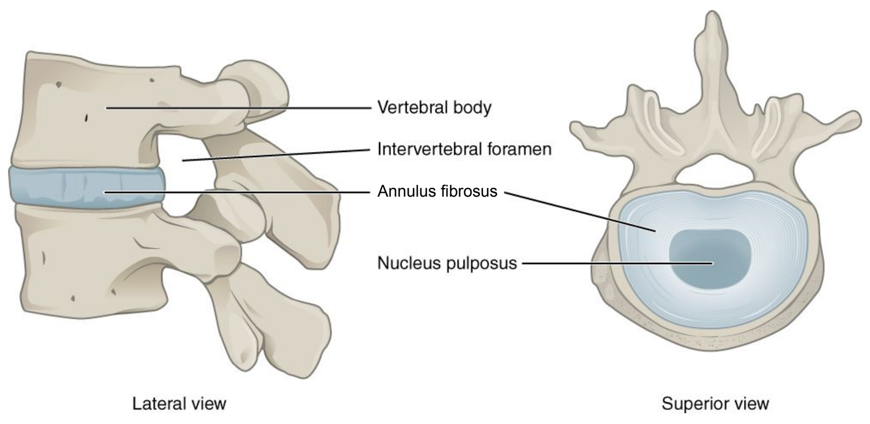

Figure 1. Anatomical representation of L4 disc region of interest. The spinal discs were modeled based on the the fourth lumbar disc (L4).

Materials and Methods

To emulate the annulus fibrosus and the nucleus pulposus silicone of durometer 37 and 2 were used, respectively. Anatomical accuracy was ensured by injecting the silicone into a custom 3D printed mold cavity for a CT based L4 disc SolidWorks model. (Figure 2)

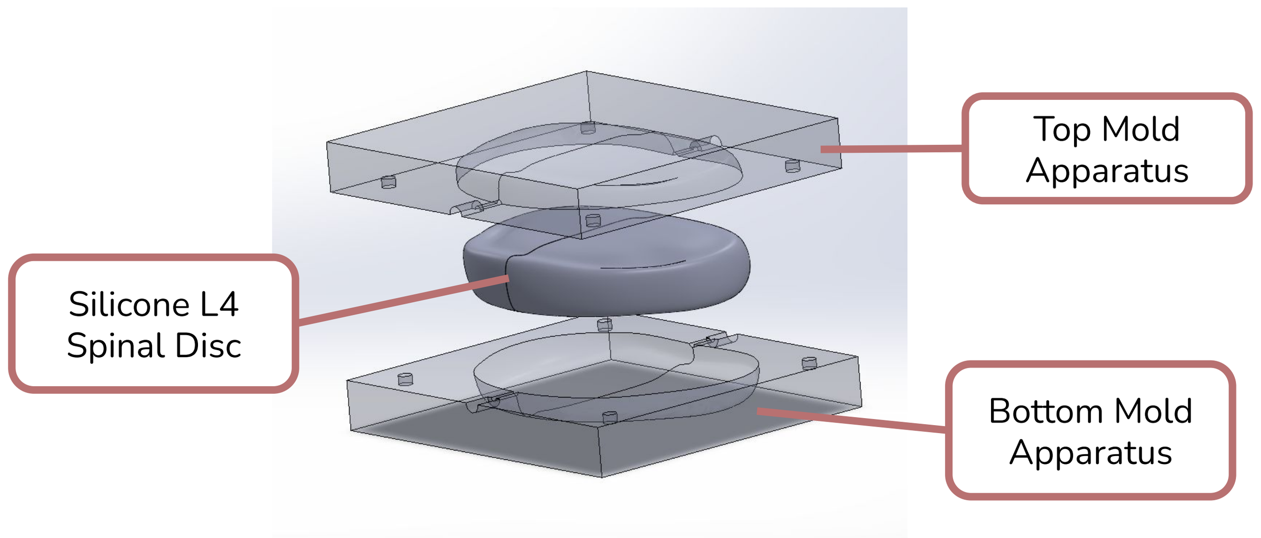

Figure 2. Exploded view of the mold apparatus model. Computer-aided design (CAD) was used to create a negative space mold of the spinal disc scan; inflow, outflow, and pin holes were added for usability.

The mold apparatus was placed inside a vacuum chamber to increase speed of injection and maintain purity of silicone. Separate injections were performed for the inner nucleus pulposus and outer annulus fibrosus. Continuous input of silicone was facilitated via caulk gun.

Mechanical stress measurements (Figure 6) were made using an Instron to compare to literature values of disc dynamics.

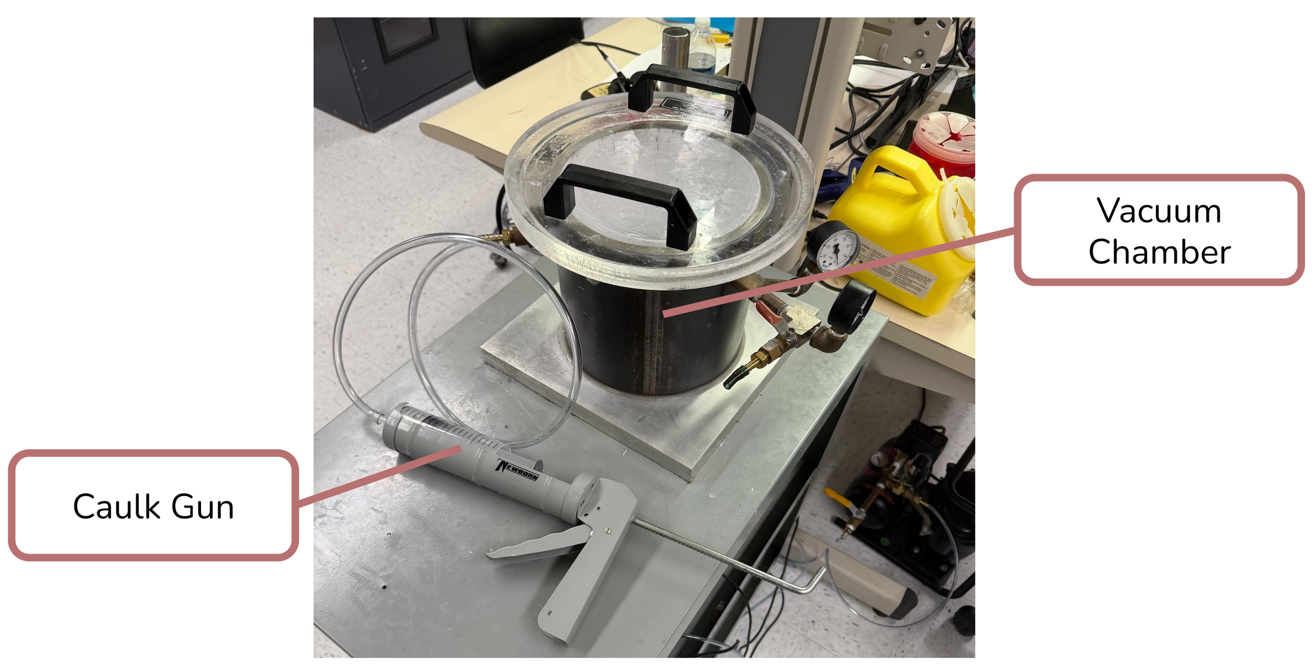

Figure 3. Vacuum chamber and caulk gun used for silicone injection process.

Results

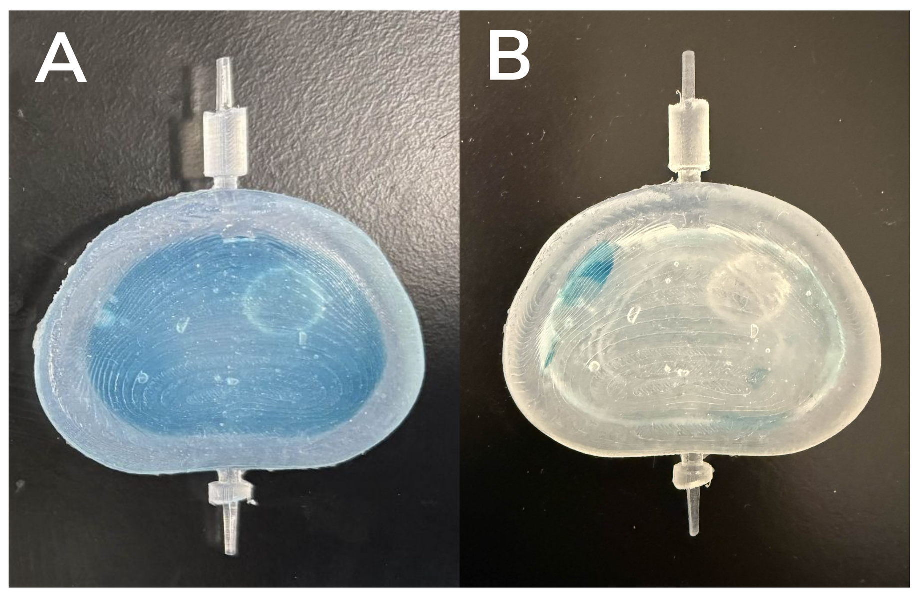

Figure 4. Evidence of silicone induced water absorption. (A) Disc state one week post injection. (B) Disc state three months post injection.

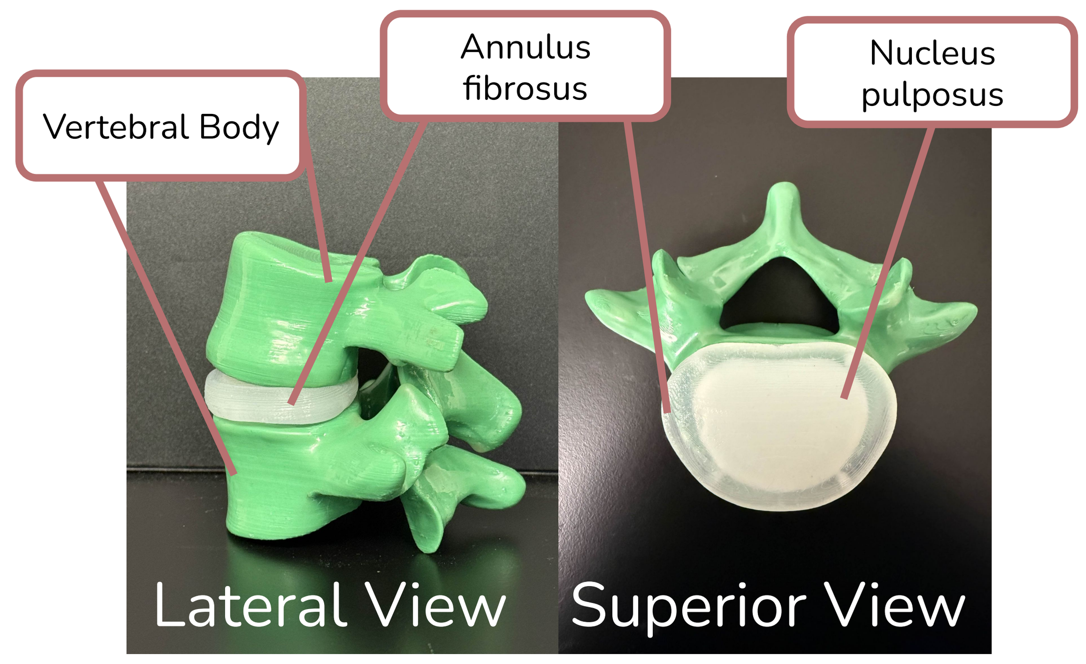

Figure 5. 3D-Printed L4-L5 lumbar vertebrae with molded silicone disc.

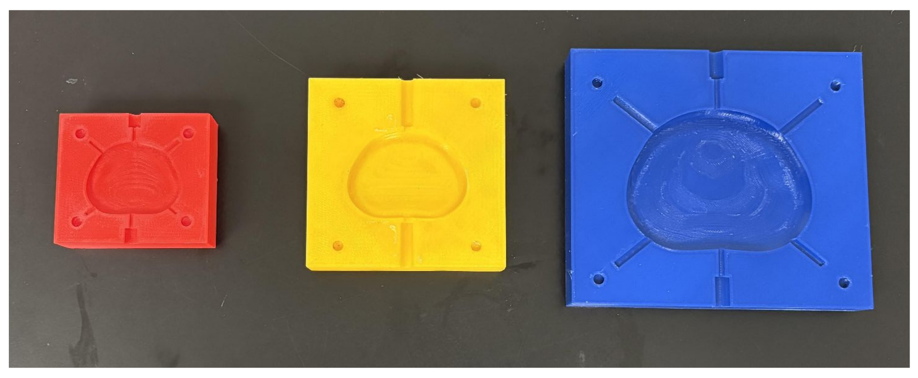

Figure 6. Iterations of spinal disc mold cavities throughout model development. Red (inner mold); yellow (outer mold); blue (inner mold for enlarged model).

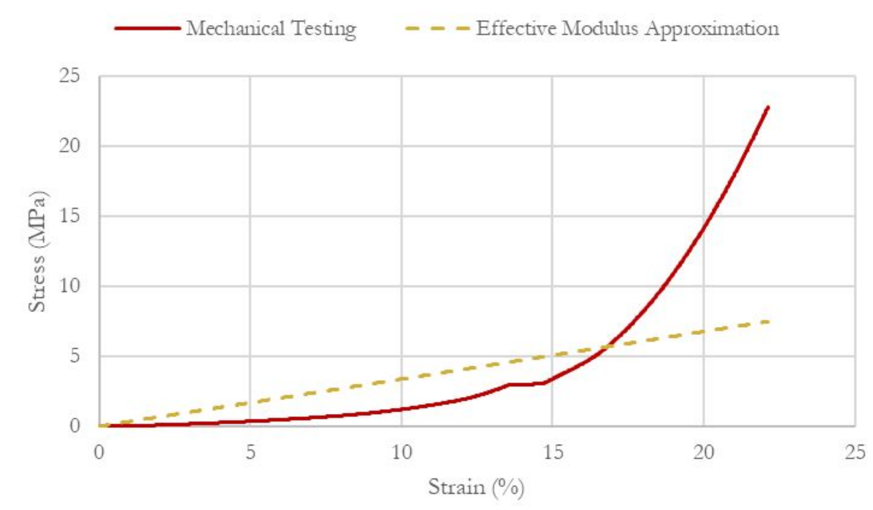

Figure 7. Stress readings of the silicon disc on the Instron. Dashed line represents approximate Young's modulus of a linear region (modulus = 33.84 MPa).

Future Expansion

Though the proposed model of the spinal disc provides a representative paradigm, a larger scale model would enhance understanding of both anatomy and physiology, by providing enhanced tactility and more distinguishable compression. Thus, a larger mold was designed to achieve this (Figure 6).

Figure 8. Incomplete outer disc injection with enlarged model, caused by excessive pressure.

Previous attempts at enlarging the model resulted in manufacturing roadblocks, namely poor scaling of fluid dynamic principles, causing increased back pressure during injection (Figure 8). Troubleshooting included refining the mold, using a ratchet caulk gun to prevent reflux, and increasing the size of the injection syringe and the tubing (Figure 9).

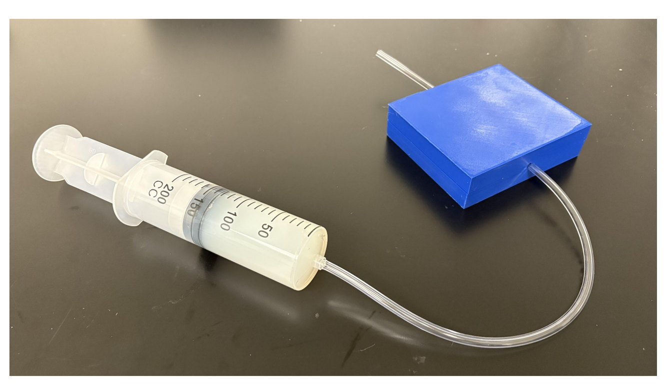

Figure 9. Mold apparatus with larger syringe and tubing for increased flow during injection.

Discussion

Initially, manufacturing of the silicone disc was attempted with a liquid core, to better model the composition of the nucleus pulposus, and attain more noticeable compression (Figure 4). However, the dyed water was absorbed by the silicone over time, leaving a pocket of air.

To maintain physiological veracity while addressing this design flaw, a lower durometer of silicone was used in place of water (Figure 5). Results show promising and biologically accurate data, with the Young Modulus of the model (33.84 MPa) falling within the expected literature range of 5.8-42.7 MPa (Figure 7).

This model will be able to accurately serve as an educational tool for neuro physical therapy students, as well as has the potential to guide patient-physician interactions.

Acknowledgments

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References

File:716 Intervertebral Disk.jpg - Wikimedia Commons. (2013, April 19). Wikimedia.org. https://commons.wikimedia.org/wiki/File:716_Intervertebral_Disk.jpg

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