Spinal Implant Design and Subsidence: Finite Element Analysis

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INTRODUCTION

Subsidence is a frequently reported mechanical adverse event for intervertebral devices. It is the vertical movement of a device into adjacent vertebrae, causing a loss of disc height (> 3mm). It occurs between 29 and 43% of cases (1) and may accelerate degeneration of adjacent spinal segments (2) resulting in vertebrae misalignment, infringement on nerve roots causing loss of sensation and pain. Our goal was to develop a Finite Element model of the spine that could be used as a design tool to verify the physical experiments and to understand internal implant stress and motion.

OBJECTIVES

Our objectives for this project were to use ABAQUS finite element software to
1. simulate a foam model used in subsidence testing experiments
2. develop a human L4/L5 finite element model
3. simulate in-vitro spine loading with a natural vertebral disc and intervertebral devices in order to measure the stress state and subsidence of spinal implants relative to vertebral bodies.

SPECIMENS

The first set of specimens that we used for this finite element analysis consisted an assembly of two foam blocks of equal geometry and materials as well as intervertebral devices made with ABS material properties from 3D printing (Fig 1). Our second set of specimens consisted of an L4/L5 spinal segment and a natural intervertebral (Fig. 2). Finally our last set of specimens consisted of the L4/L5 segment (3) and intervertebral spinal implant devices (Fig. 3).We assumed hyperfoam properties for the natural disc, 100MPa stiffness for trabecular and 10000MPa stiffness to cortical bone (4).

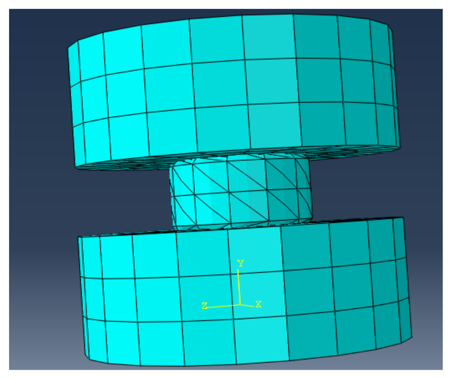

Figure 1. Foam Assemblies

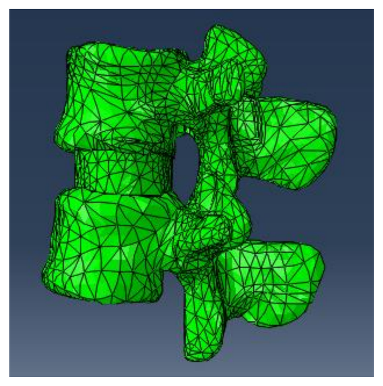

Figure 2. Natural Assembly

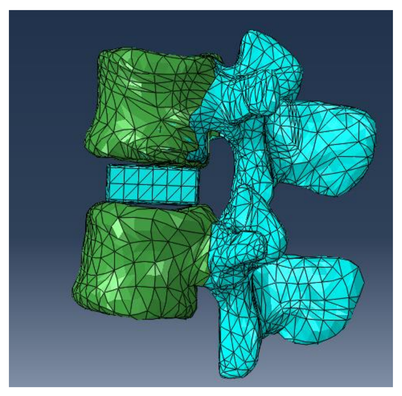

Figure 3. Corticated Assembly

FINITE ELEMENT MODELS

The foam blocks were built in ABAQUS with the same geometries and material properties as the physical blocks used in our experiments. Intervertebral devices designed for experiments were imported into ABAQUS and positioned between the two foam blocks (Fig. 1). We constrained the interacting surfaces and applied a compressive load of 1000 N. We assigned hex elements to the mesh of the foam blocks and tetrahedral elements to the mesh of the implant devices. For the L4/L5 Spinal Segment model, a cortical bone shell was created to surround the inner trabecular bone. To do this, an offset mesh was created at a distance of 0.29 mm (5). We used two different methods to simulate the L4/L5 model:Corticated (Fig. 3, 4) and decorticated (Fig. 5). The shell was decorticated using the merge/cut instances command in order to achieve maximum contact of the vertebral bodies and the intervertebral devices. In order to simulate moderate daily activity we applied a compressive load of 1000 N on the top vertebral body and fixed the bottom vertebral body in the assembly using boundary conditions (5). We used tetrahedral mesh elements for the vertebral bodies, the natural disc and the intervertebral implant devices. Similar to the foam model, we constrained the interacting surfaces of the vertebral bodies and surfaces of the intervertebral disc/implant devices.

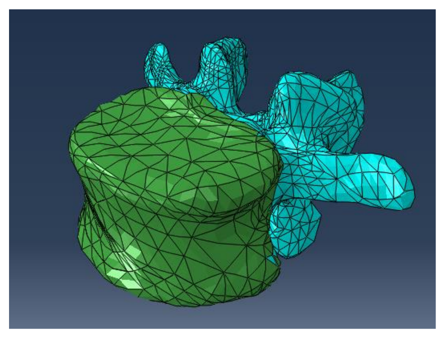

Figure 4. Cortical Shell

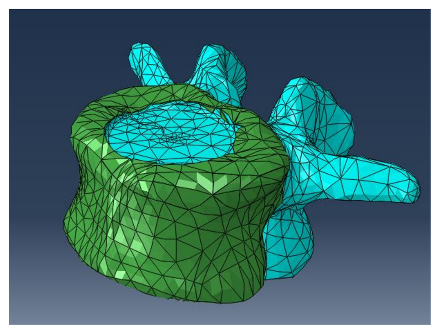

Figure 5. Decorticated

RESULTS

We simulated the foam with the intervertebral devices to measure the stress state and subsidence. The devices with a smaller area had a higher concentration of stress (Fig 6). There was also an increase in subsidence with decreasing implant size.

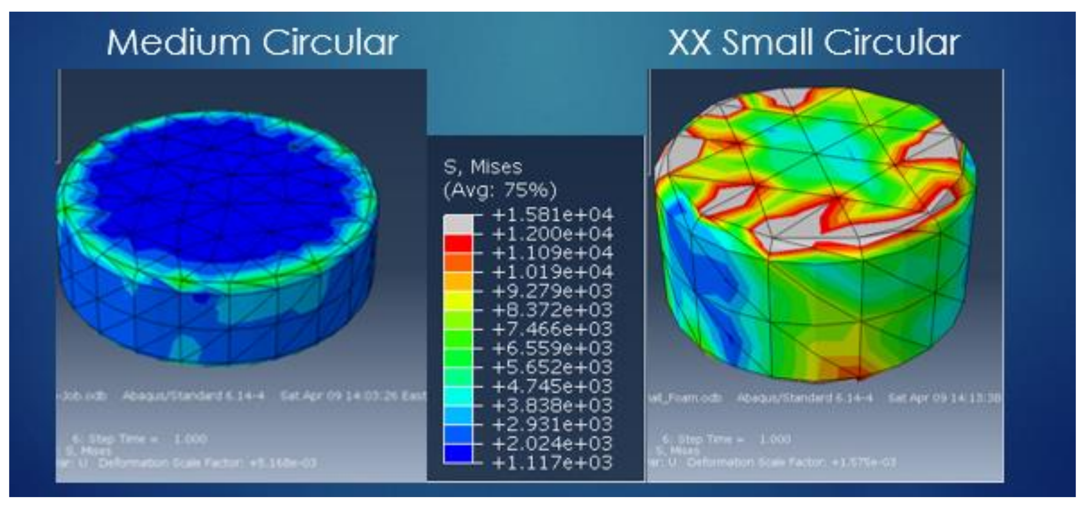

Figure 6 Foam Simulations

We simulated the spine model with a natural intervertebral disc (Fig. 7).

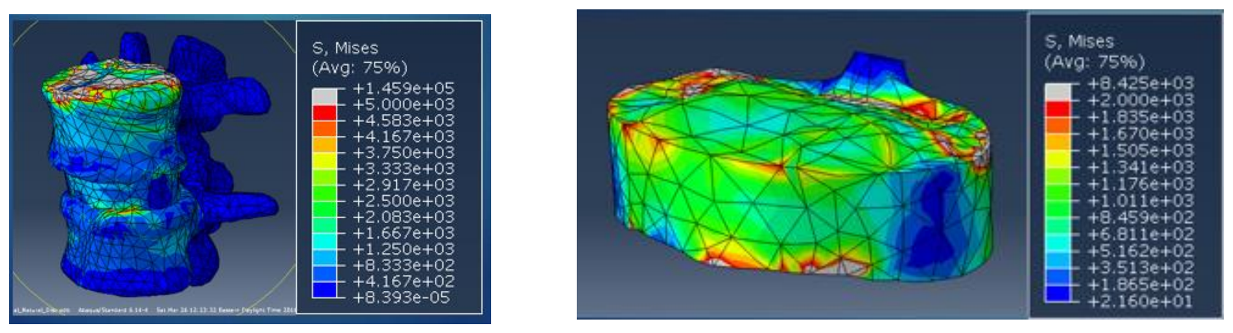

Figure 7. Natural Spine Model

As for the spine model with intervertebral devices we achieved similar results as the foam model for both corticated and decorticated vertebral bodies. The stress concentration increased as the implant area decreased. Subsidence was measured the position of the intervertebral devices before and after loading. A smaller area is seen to have an increase in displacement (Fig. 8).

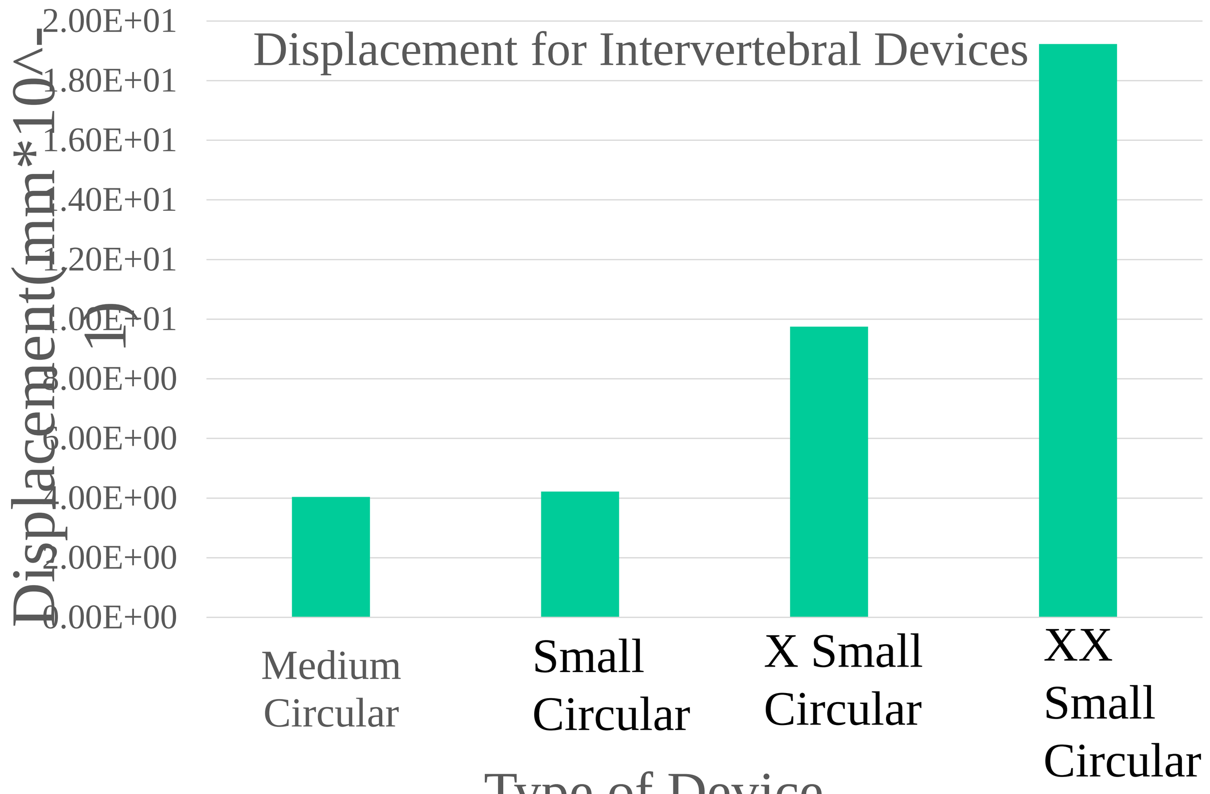

Figure 8. Subsidence Measurement

CONCLUSION

The stress state on our Natural Intervertebral Disc was similar to published data (5). As seen in our results, we can conclude that a smaller area will result in higher stresses acting on the intervertebral devices for both corticated and decorticated vertebral bodies. We can also conclude that as the implant footprint (area) decreases the displacement will increase and therefore the amount of subsidence will increase. This matched experimental results.

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