Analysis of Pedicle Screw Placement in the Lumbar Spine

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ABSTRACT

Back pain can be defined, generally, as pain felt in the dorsal area of the human body. In the United States, statistics show that 70-85% of all people experience back pain in some point of life. Severe lumbar back pain treatment may require surgery in order to reduce the pain experienced and restore the natural range of motion of the spine.

Spinal fusion occurs when metal parts are used to fuse together vertebrae. Currently surgeons examine patients and use general parts to fuse the spine. However, due to the complexity of the spine geometry and the skill of the surgeon success rates vary. In this study, Finite Element Analysis is used to help determine the optimal location for the attachment of the metal parts during spinal fusion surgery. The optimal location will allow the fabrication of a spinal drill guide to help surgeons accurately attach the metal parts to the lumbar spine tailored to the patient. This research could help promote the collaboration between engineers and orthopedic surgeons.

INTRODUCTION

Spinal Fusion

- Surgery is used to treat deformities caused by traumatic fractures to restore stability to spine by fixing the vertebrae of interest
- Commonly used to correct abnormalities in the lumbar region
- Surgery corrects advance forms of:
  - Spinal disc herniation
  - Degenerative disc disease
  - Pain
  - Scoliosis
- Posterolateral fusion, bone graft is fixed to posterior and vertebrae are fixed with screws through the pedicles of each vertebrae attaching to a metal rod on lateral sides of the vertebrae
- Surgery attempts to promote osteoblasts activity to cause bone fusion of the vertebrae together

Current Spinal Fusion Problems

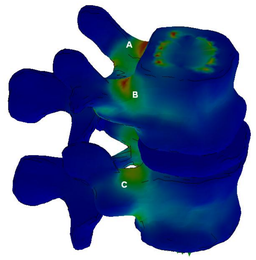
- Fusion failures due to lack of osteoblast stimulation due to poor surgical implementation
- Hardware failure due to weak fixation and insufficient bone remodeling
- Poor fixation hardware may cause pressure sores and result in pain
- Surgeon attachment of hardware depends on his skill level

PURPOSE

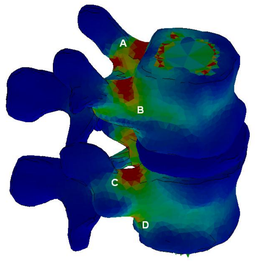
- Investigate current methods used in spinal fusion surgery
- Create model for the lumbar region of the spine using CT scan
- Apply Finite Element Analysis (FEA) to determine optimal fixation location for pedicle screws on lumbar spine
- Provide data in order to design a drill guide to help surgeons perform spinal fusion surgery

RESULTS

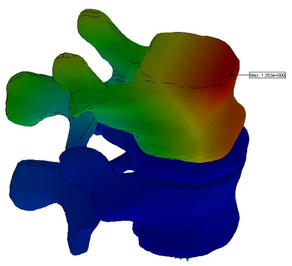
Centered Case



Stress
- Maximum stress occurs in region A with a value ~ 3.0 MPa
- Contours show concentration of stress near the pedicle petrusions



Strain
- Max strain is found to be on the L3, regions A & B
- Less strain is on the L4, which probably is due to the load being applied to L3



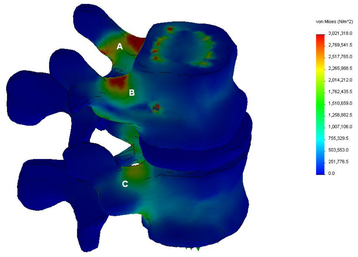
Displacement
- Max displacement occurs near anterior of L3 with a value of 1.353 mm
- There is a slightly more displacement in the center case

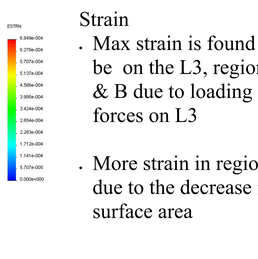
Stress (Pa)

Region	Centered	Un-centered	% Increase
A	2873736	3712388	29%
B	3049021	3367942	10%
C	2061047	2115484	3%

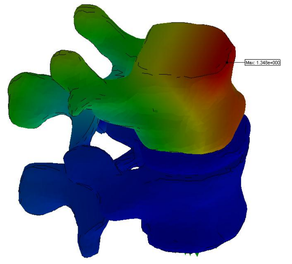
Un-Centered Case

Stress
- Maximum stress occurs in region B with a value ~ 3.4 MPa
- This is probably due to the right pedicle screw being moved laterally





Strain
- Max strain is found to be on the L3, regions A & B due to loading forces on L3
- More strain in region A due to the decrease in surface area



Displacement
- Max displacement occurs near anterior of L3 with a value of 1.348 mm

Strain

Region	Centered	Un-centered	% Increase
A	9.655e-04	1.354e-03	40%
B	9.616e-04	1.062e-03	10%
C	2.152e-04	4.902e-04	128%
D	5.647e-04	5.922-04	5%

CONCLUSIONS

- Areas where the screw had moved 3 mm experienced an increase in stress and strain as shown in the results
- The increase in stress and strain is due to the change in thickness of the pedicles where the screws are attached
- FEA analysis allows the design of drill guides to provide accurate attachment of pedicle screws to patient

- Custom drill guide is specific to geometry of the patient
- Note the holes that the surgeon can use to accurately attach the pedicle screws to the lumbar vertebrae

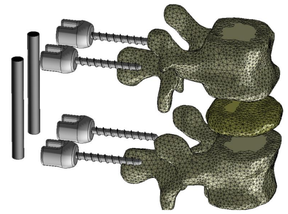
METHODS

Experimental Approach

- 40 slices from DICOM images of a spinal CT scan were used during image segmentation and smoothing to convert the lumbar spine CT scan into a 3D model
- Simpleware ScanIP used for image processing
- Final 3D model from ScanIP image processing consisted of the L3 and L4 vertebrae and the intervertebral disc between them
- SolidWorks was used to construct and analyze the pedicle screw placement

Pertinent Data

- Pedicle screws are 47 mm long with screw major diameter of 4 mm
- Rods are 36mm long and 5.2mm in diameter
- Vertebrae are ~ 26.25 mm long by 73mm deep
- Disc thickness is ~ 8.75 mm



Material Property	L3 & L4 Vertebrae	Intervertebral Disc	Pedicle Screws (Ti-6Al-4V)
Young's Modulus	92 MPa	172.4 MPa	104.8 GPa
Poison Ratio	0.3	0.3	0.31
Density	0.32 Kg/m^3	905 Kg/m^3	4428.7 Kg/m^3
Yield Strength	52 MPa	6.9 MPa	1.05 GPa

Design Criteria & Simulation Assumptions

- Isotropic bone properties for L3 and L4
- Disc assigned mechanical properties of HMWPE
- L4's bottom facet is fixed
- Facets touching intervertebral disc are locked to the disc
- Flexion in the spine and no rotational movement
- Pedicle screw heads are rigid relative to screws
- Screws replaced with circular shafts for FEA
- Two cases are simulated: one where pedicle screws are centered to the pedicle and one where pedicle screws are offset (top-left pedicle screw moved proximally by 3mm and top-right pedicle screw moved laterally by 3mm)
- Mesh:

Jacobian Points	Element Size	Tolerance	Total Nodes
4 points	4.39889mm	0.219944mm	154839

Governing Theories

- von Mises stress, strain , and displacement were measured while the spine is loaded to cause 1.5° flexion for both simulated cases

$$\sigma_v = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2}{2}} \qquad \epsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$