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A Study of Biomechanical Behaviour of Lumbar Vertebra L2-L4 Region for Osteoporosis Condition in Endplates

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Abstract

Objectives: To model and analyze the osteoporotic lumbar vertebra L2-L4 region and predict the stress patterns for different loading condition. **Methods:** Osteoporosis is a disease in which low bone mass density and micro deterioration of bone tissue causing bone fragility and high risk of fracture. Using the dry bone, the dimensions are measured and are compared with the literature dimensions. Based on these dimensions L2-L4 lumbar vertebral segment was modeled and meshed. Finite element model was developed to analyze the biomechanical properties of the vertebral body because of its complex anatomy. **Findings:** Intact model is validated for various range of motions and compared with the literature. Displacement in the end plates of vertebra are found and compared with the intact model. **Applications:** Implant for the osteoporosis patient can be designed using this Biomechanical study and can be analyzed for different loading conditions.

Keywords: Endplates, Finite Element Analysis, Lumbar Vertebra, Osteoporosis

1. Introduction

The human spine has 24 spinal bones, called vertebrae, which are arranged one above another to form the spinal column. The spinal column is the main support and the compressive load acts on the lumbar vertebra. The vertebral bone is composed of porous trabecular bone and surrounded by a thin cortex. In osteoporosis, bone mineral density is lower in the cortex region, which leads to weakness. Osteoporosis is a disease in which low bone mass density and micro deterioration of bone tissue causing bone fragility and high risk of fracture. Osteoporosis is common disease affecting both men and women, and it is more prevalent in our aging society. Osteoporosis is classified with its T-score, which is compared with an average young adult: for normal it is above −1.0; for osteopenia it's above −2.5 and below−1.0; for osteoporosis its below−2.5; severe osteoporosis is the presence of one or more fragility facture. About 1.5 million fractures are reported annually in the United States due to osteoporosis, including around 700,000 vertebral fractures. Survival is about 72% in the first year and only 28% after five years[1].

Due of complex anatomy and geometry of the vertebral body, finite element models was developed including ligaments to analyze the biomechanical behavior of the vertebral body

2. Materials and Methods

Dimensions of dry bone are measured using the digital Vernier calliper. The obtained dimensions are compared with the literature values[2]. These dimensions are used for model the vertebrae using CATIA V5.

Various dimensions measured are Lower end plate width, Upper end plate width, Upper end plate depth, Lower end plate depth, Transverse process width, vertebral body height, Spinal canal width and Spinal canal depth. The values are shown in Table 1.

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Table 1. Comparison of L2 Dimensions

Vertebra dimensions	Dry bone (mm)	Reference (2)
Lower end plate width	47.34	48.66
Upper end plate width	42.9	44.9
Upper end plate depth	29.8	33.27
Lower end plate depth	32.4	34.35
Transverse process width	66.7	75.64
Vertebral body height	25.7	24.42
Spinal canal width	19.9	22.93
Spinal canal depth	16.02	13.76

Using the dimensions from the previous study, vertebra is modeled and is shown in the Figure 1. Meshing is done using hyper mesh with solid 45 element. Outer cortical bone is 0.35mm thickness and the inner trabecular bone is separated from the outer bone using hyper mesh.

The dimensions of the intervertebral disc and material properties are taken from the previous study[3]. L2-L4 vertebra assembly is done using catia with the obtained dimensions.

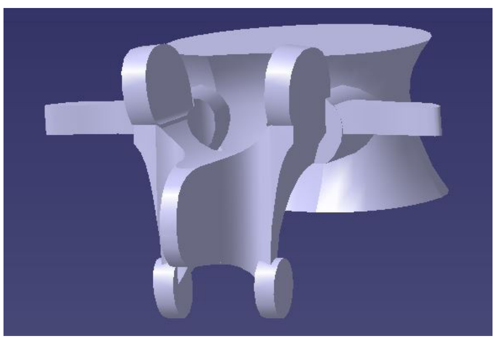

Figure 1. Model of L2 vertebra.

Table 2 Shows the material properties of the normal and patient with osteoporosis. These properties are taken from the previous study[4].

Table 2. Material properties of lumbar vertebra

Bone parameters	Young's Modulus (MPa)	Poisson's Ratio
Cortical bone	12000	0.3
Cancellous bone	100	0.3
Nucleus	1	0.499
Annulus	8.4	0.45
End Plates	24	0.4
Facet contact	100	0.3
Cortical(Patient)	6495	0.3
Cancellous(patient)	264	0.2

The Figure2 shows the assembly of L2-L4 vertebra with intervertebral discs. The facet contact gap is 0.5mm and meshing is done using hyper mesh. Cortical (0.35mm), cancellous, annulus, nucleus and end plates are separated according to the exact dimensions from the literature. Cortical and cancellous bone is separated using hyper mesh and endplates are also added to the meshed component. Facet contacts are given as a frictionless contact.

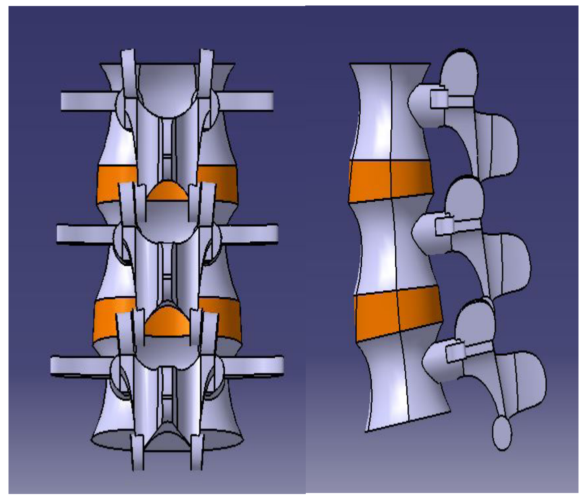

Figure 2. Assembly of L2-L4 with intervertebral disc and endplates.

The Figure 3 shows the meshed model of L2-L4 with intervertebral discs and end plates. The ligaments are given as 1-D rod elements with their own cross section.

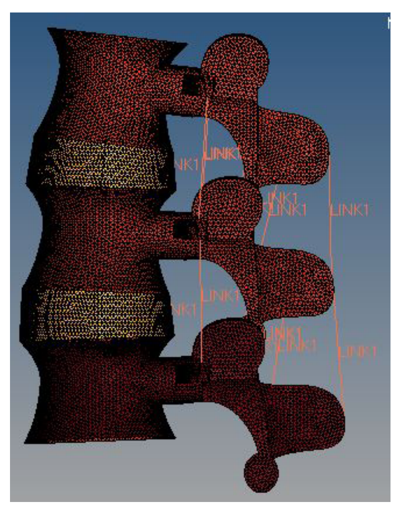

Figure 3. Meshed model with ligaments, discs and endplates.

Figure 4 represents the separated cortical and cancellous bone. The analysis is carried out using ansys software with the boundary conditions stated in the literature and the results are compared for the normal and osteoporosis condition[5].

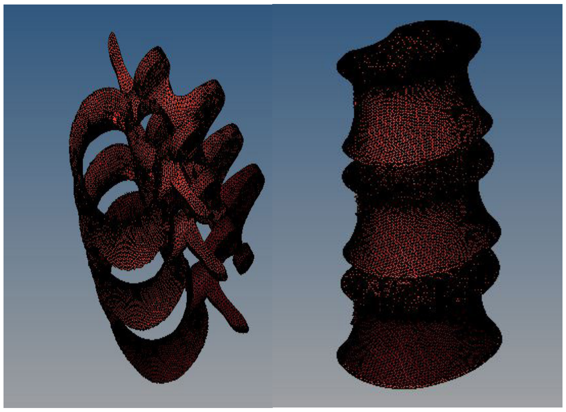

Figure 4. Segregation of cortical and cancellous bone from the model.

3. Result and Discussion

3.1 Finite Element Analysis of L2 Vertebra

The results for the normal (L2) and osteoporosis (L2) patient were compared. Compressive load of 1500N is applied as shown in Figure 5 at the top of endplate and displacements at the bottom nodes are arrested. In normal patient von-mises stress are about 8.1 MPa and the maximum displacement (0.5) mm is obtained at the centre of the end plate.

For osteoporosis patient von-mises stress are obtained as 8.14 MPa and maximum displacement as 1.6 mm. Thus from the results it is concluded that the patient with osteoporosis is subjected to maximum stress and displacement at the centre of the end plates. Results are compared and the intact model is validated and shown in Figure 6.

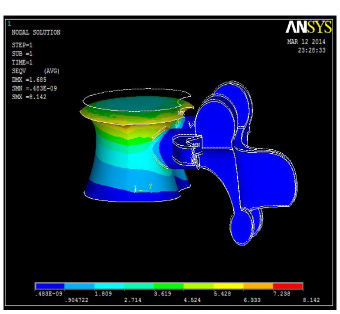

Figure 5. Analysis of L2 vertebra with compression loading.

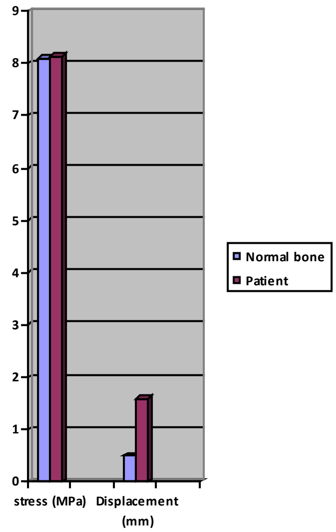

Figure 6. Result comparison of L2 for intact and osteoporosis condition.

Since the results are validated, assembly of L2-L4 vertebra is modeled and analyzed for normal as well as osteoporosis condition. The results show that displacement values are higher for the osteoporosis patient when compared to the normal person.

3.2 Finite Element Analysis of L2-L4 Vertebra

The results for the normal and osteoporosis patient are compared for the load of 720N. Boundary conditions are applied such that bottom nodes are fixed and compressive UDL load is applied at the top of L2 endplate and shown in Figure 7.

The stress and displacement values are compared for normal and osteoporosis patient. Maximum stress obtained for normal and osteoporosis conditions are 8.78 MPa, 8.92 MPa respectively.

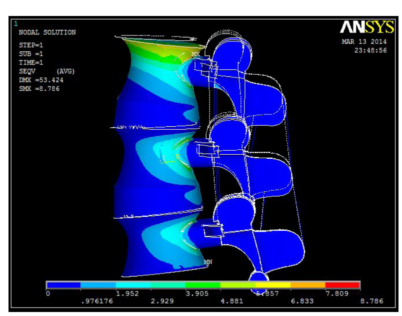

Figure 7. Compressive analysis of L2-L4 region with Ligaments, intervertebral disc and endplates.

Comparison of displacement values of L2, L3 and L4 upper endplate in normal bone and patient are shown in graph Figures 8 - 10. The values of the osteoporosis patient are higher than the normal bone.

The movements of the endplate nodes are higher in the middle and lower at the anterior and posterior side. This may cause fracture in the bone.

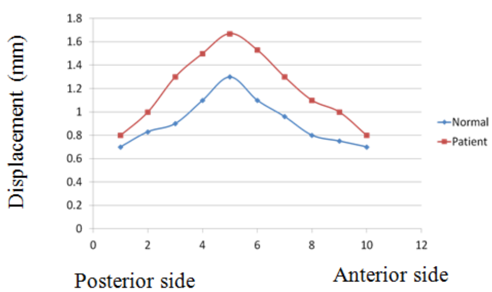

Figure 8. Comparison of L2 End plate displacement (mm) from posterior to anterior nodes.

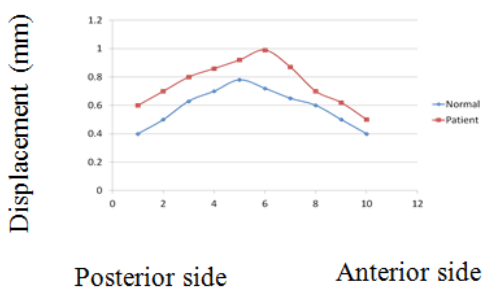

Figure 9. Comparison of L3 End plate displacement (mm) from posterior to anterior nodes.

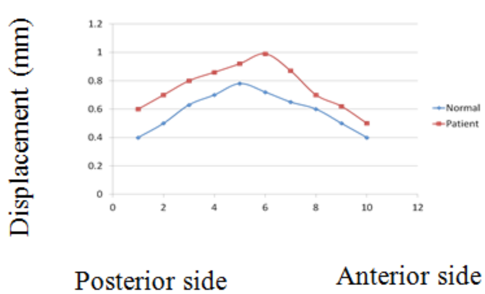

Figure 10. Comparison of L4 End plate displacement (mm) from posterior to anterior nodes.

4. Conclusion

In this study, intact model of lumbar vertebra is modeled and analyzed. The displacement values of the normal and osteoporosis patient are determined for the compressive loading. From the obtained results, patient with osteoporosis is subjected to more stress and displacement in the upper end plate. In L2-L4 vertebra, the displacement results of upper endplates are higher in all the three vertebrae for osteoporosis condition compared to normal condition. Thus it leads to vertebral compression fracture in the trabecular bone for high loading conditions. Stress and displacement results in the vertebra for osteoporosis condition may be considered for designing an implant for patient specific condition.

5. References

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