

A BIOMECHANICAL STUDY ON LUMBAR SPINE SEGMENT OF L1 AND L2 FOR A HEALTHY BONE USING FINITE ELEMENT METHOD

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Abstract: Finite element modeling (FEM) is a powerful and efficient tool for modeling and simulation of the biomedical engineering system. This study is used to implement the finite element modeling techniques to understand the biomechanical behavior of lumbar spine segment. At present, there are few studies that report three-dimensional movement analysis of lumbar spine regions. . The objective of this study was to develop a finite element model of human lumbar spine segment L1-L2 to predict the stress concentration and range of all physiological motions for the compression load and the pure moment of 10 Nm. The Range of motion (ROM) and von mises stress under all loading and physiological conditions were examined and compared with the literature.

Keywords: Biomechanics, Finite element modelling, Lumbar spine, Physiological motions.

1. Introduction

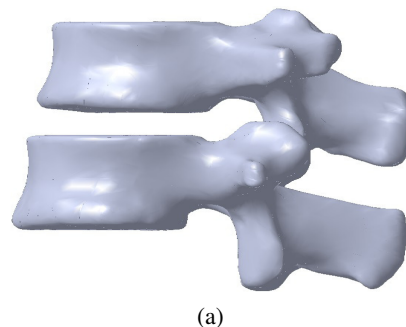
Spinal kinematics concerns with the motion of the human spine undergo during its normal physiologic movements. The spinal column is made of 26 Vertebrae stacked one on top of the other bone. This spinal column gives the fundamental support to our body, enabling us to stand upright, curve, turn and furthermore shielding the spinal line from damage. Research in this area of spinal biomechanics provides the current information about the ranges of motion of the human spine for various vertebral segments and in different directions [1]. A healthy spine of our body was contributed by robust muscles, bones, ligaments, versatile tendons and delicate nerves. Any of those structures littered with injury, strain or sickness will cause pain. In these types of situations, abnormal motions were certainly one of the signs of typical symptoms of instability. So knowledge of normal movements of the lumbar spine is necessary to evaluate the abnormal motions.

Finite element analysis is a common method used to study the biomechanics of the human lumbar spine.

Currently Various lumbar spine FE models was developed in the literature. Dong et al. [4] developed a L2–L5 lumbar spine FE model based on a computerized tomography (CT) scan to study the stiffness of the dynamic stabilizing device and the range of motion for the intact lumbar segment. Chunyu, Qinghua, et al. [6] created a L1-L2 lumbar spine FE model based on a CT scan of healthy male subject. An axial compressive load was applied to this model to predict stress concentration on intervertebral disc. In the present study the finite element model of lumbar spine segment L1-L2 was developed and analyzed under axial compression load and moment to predict the displacement and range of motion, then it was compared with literature.

2. Materials and Methods

The finite element model of lumbar spine segment L1-L2 was extracted from the computed tomography (CT) scan images of healthy male subject using commercial 3D reconstruction software Mimics then the 3D data was edited to get a smooth surface using geomagic Design X. The geometric data's of the endplate and disc was difficult to extract from CT scan images so that the regions between the reconstructed vertebral bodies L1 and L2 were modeled using the solid modeling software CATIA V5. Then the model was exported to Hypermesh 13.0 to generate mesh using 4 node tetra element was shown in Figure 1.



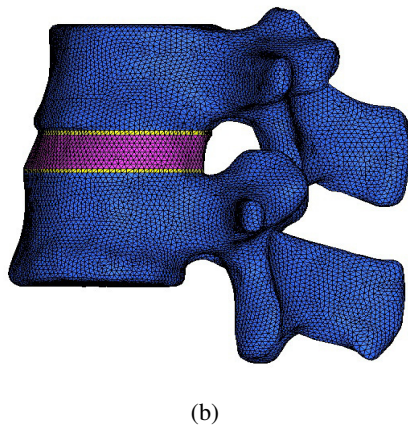


Figure 1. FE model (a) extracted from CT scan; (b) Meshed model.

The finite element model of vertebral segment was segmented into five different components are shown in Figure 2.

- Cortical
- Cancellous
- Endplate
- Annulus
- Nucleus

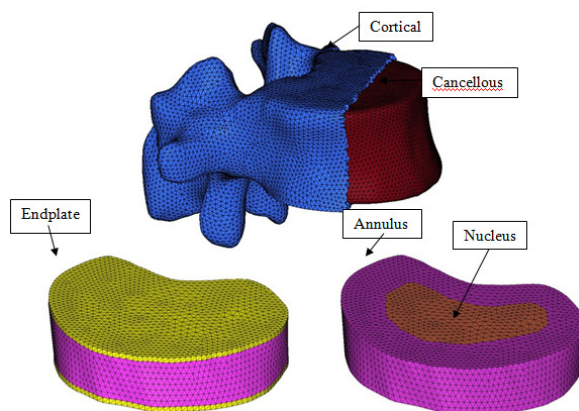


Figure 2. Segmentation.

Vertebrae consist of cancellous surrounded by shell layer cortical with a thickness of 1 mm. At top and bottom ends of the disc have endplates with a thickness of 0.5 mm. A three dimensional solid element SOLID 185 was used for meshing cortical, cancellous, endplate, annulus and nucleus. The facet joints were connected as a surface to surface contact with an initial gap of 0.5 mm and the friction coefficient of 0.1. These contacts were only able to transmit compression forces but not tension. All seven ligaments of lumbar spine are added to the FE model and considered as link element, as shown in Table 1.

Table 1. Element type used in FE model

Components		Element type
Vertebrae	Cortical,Cancellous	Solid 185
Disc	Endplate, Annulus, Nucleus	Solid 185
Face joint	Contact surface Target surface	Contact 173 Target 170
Ligaments		Link 10

3. Material properties

The material properties used in this study were adopted from the literature [4 & 5] and are listed in Table 2.

Table 2. Material properties used in FE model

Components	Young's modulus (MPa)	Poisson's ratio	Cross section area (mm ²)
Cortical	12000	0.3	-
Cancellous	100	0.2	-
Endplate	24	0.4	-
Annulus	4.2	0.45	-
Nucleus	1	0.499	-
ALL	20	-	63.7
PLL	20	-	20
TL	58.7	-	3.6
LF	19.5	-	40
ISL	11.6	-	40
SSL	15	-	30
CL	32.9	-	30

4. Boundary and Loading Conditions

The bottom surface of the L2 vertebral body was completely fixed in all directions. The force/moment was given to the top surface of the L1 vertebral body in all physiological directions flexion/extension, lateral bending, and torsion, as shown in Figure 3.

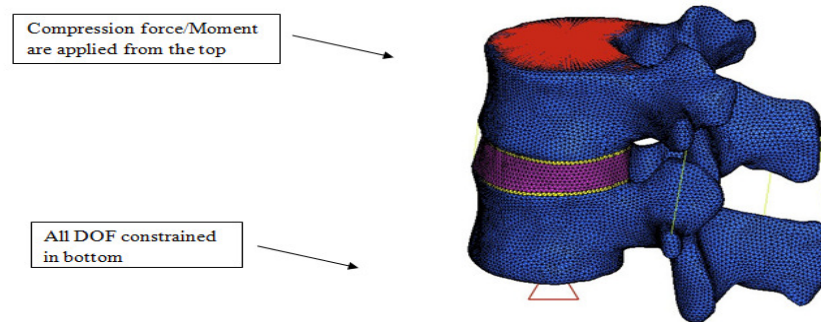


Figure 3. Meshed model with boundary conditions

5. Results and Discussion

5.1 FE model validation

First step in the validation process was to validate FE model parameters by comparing them with the literature. The data obtained from the present FE model was compared with the study of Yamamoto et al. [2]. The same loading conditions were used for the validation process. This study presents the results in two parts. First the stress distribution in the vertebral body was presented. Second, the physiologic movements the lumbar spine under the moment of 10 Nm was compared with literature.

5.2 Compression load test

The FE model was tested under the axial compression load of 100 N and it was gradually increased up to 300 N in steps of 50 N to analyze the stress distribution of lumbar spine segment L1-L2. The maximum stress was found at a middle portion of upper vertebra L1 and just below to the face joint of L2. The maximum displacement happened at facet location on upper vertebra L1 was shown in Figure 4. The stress distribution and displacement of both vertebrae were examined and listed in Table 3

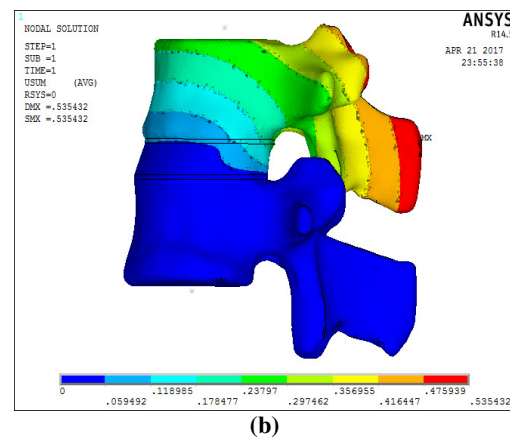
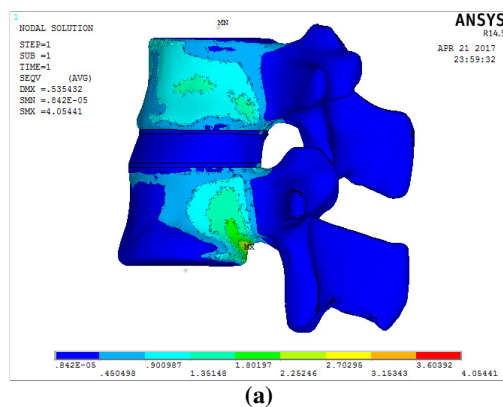


Figure 4. FE analysis (a) Stress distribution; (b) Displacement.

Table 3. Stress distribution and displacement

Force (N)	Von Mises stress (MPa)	Displacement (mm)
100	2.70	0.37
150	4.05	0.53
200	5.40	0.74
250	6.75	0.92
300	8.10	1.11

5.3 Range of motion

To evaluate the three dimensional physiologic movements the lumbar spine was subjected to the pure moment of 10 Nm (flexion, extension, torsion and lateral bending) on the superior surface of the upper vertebral body L1, as shown in Figure 5. The ROM of both vertebral bodies were examined and compared with the result of experimental study performed with the same type of loading conditions are listed in Table 4. FE model, the maximum motion on vertebra body

occurred in flexion and extension but it was slightly greater than the Yamamoto study. In flexion, extension and lateral bending ROM has a 0.15% variation with literature but in axial rotation ROM are 30% higher. The main reason for this variation was in this study we didn't consider the full segment model of lumbar spine. The literature value was based on the full segment of lumbar spine specimen.

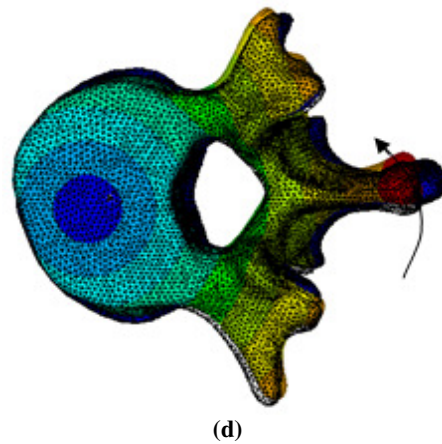
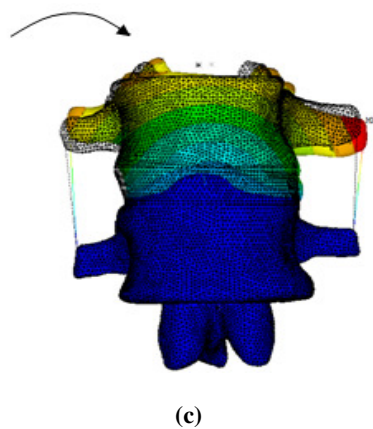
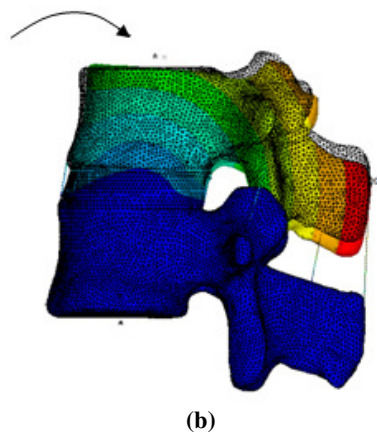
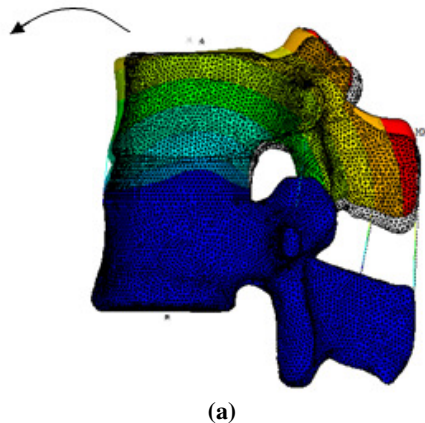


Figure 5. ROM (a) Flexion; (b) Extension; (c) Lateral bending; (d) Axial rotation.

Table 4. Comparing ROM of lumbar segment L1-L2 with literature

Moment (Nm)	ROM of L1-L2 in degrees	
	Present study	Yamamoto at el (1989).
Flexion	5.55	5.8 (0.6)
Extension	4.98	4.3 (0.5)
Lateral bending right	5.33	5.2 (0.4)
Lateral bending left	5.27	4.7 (0.4)
Axial rotation right	3.64	2.0 (0.6)
Axial rotation left	3.60	2.6 (0.5)

These results indicate data obtained from the FE analysis correlated well with the literature and within limit. Graphical representations of this comparison are shown in Figure 6.

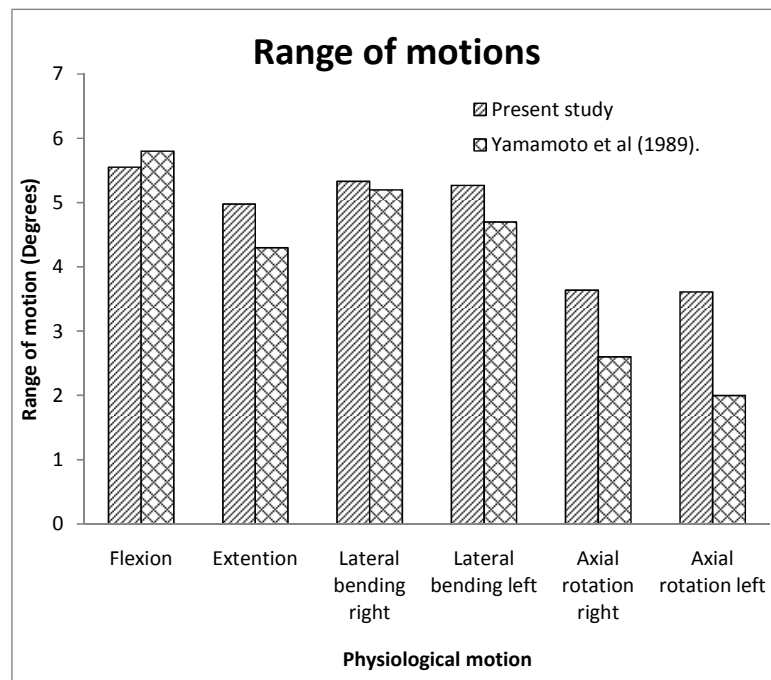


Figure 6. Comparison between FE model and experimental study

6. Conclusion

In the field of biomechanics, finite element method (FEM) can be proven powerful and efficient tool. To evaluate biomechanical behavior lumbar spine a three dimensional FE analysis was performed on lumbar spine segment L1-L2. The FE model of L1-L2 segment was tested under the axial compression load. The moment results of ROM were compared to the results of Yamamoto study. Axial rotation was slightly higher compares with the other physiological motions. The data from the FE analysis correlated well with the literature. So the results of this study confirmed the finite element model developed in this study may be trusted and it will be used for further study of defected condition and development of full spine segment.

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