VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

A BIOMECHANICAL STUDY OF LUMBOSACRAL TRANSITIONAL VERTEBRAE (L4/S1) USING FINITE ELEMENT METHOD

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ABSTRACT

Biomechanics helps us to study the mechanical behaviour of the musculoskeletal system and it provides direction for the clinician to develop the treatment protocol. The objective of this study is to develop a finite element model of the LSTV (lumbosacral transitional vertebra) lumbar spine (L4 vertebrae and sacralisation model). In this study, cadaveric bones are used to measure geometrical data of the human spine vertebrae and sacralisation. Based on the measured data of the vertebra figuration, a detailed three-dimensional linear finite element model of the lumbosacral joint L4-S1 of the spine was created and investigated the biomechanical properties of the lumbosacral junction. The finite element model was finely developed for L4/S1 (LSTV) model and validated according to available experimental results and finite element results of L5/S1. The load (stress) distributions in that region is studied for defected model, along with the range of motion for all physiological motions namely flexion, extension, lateral bending and axial rotation for lumbosacral transitional vertebrae . The results of L4-Sacralisation conclude that the physiological motions will be reduced when compared with the intact model.

Keywords: spine, lumbar spine, sacralisation, and finite element method.

INTRODUCTION

Anatomical difference between L5-S1 and L4-S1 results in structural variation, disc pressure variation in the biomechanical responses. The lumbar spine consists of five vertebrae, intervertebral disc between each vertebra. Sacral region is located below the lumbar spine. Functions of lumbar spine include structural support, movement, and protection of certain body tissues. The sacrum is a series from S1 to S5 and 5 bony segments fused together. The lumbosacral joint or L5-S1 joint is where the lumbar spine meets sacrum. The sacrum distributes force transfer to it from the upper body. In the development stage during the segmentation of the lumbosacral spine this defect occurs commonly. Lumbosacral transitional vertebrae (LSTV) are congenital anomalies in the lumbosacral region, it includes sacralisation of fifth lumbar vertebra and lumbarisation of first sacral vertebra observed [1]. Sacralization of the fifth lumbar vertebra (or sacralization) is a congenital anomaly, found in which the transverse process of the last lumbar vertebra (L5) fuses to the sacrum on one side or both shown in Figure-1. In the statistical survey this anomalies are observed around 3.5 percent of people, and it is usually bilateral. Although, sacralization may be a cause for the low back pain, it is asymptomatic in many cases (especially bilateral type)[4]. Commonly the low back pain in these cases occurs due to improper anatomy and chronic faulty biomechanics. The lumbosacral joint is different from these lumbar spine joints. So, it is proposed to identify the cause for back pain and the problem of human being with sacralisation of L4 vertebrae with sacrum. It is also essential to understand the biomechanics of lumbosacral joint by applying various loading and boundary conditions. So, it is proposed to study the range of motion in lumbosacral transitional using Finite Element Modeling as given in Table-1

Figure-1. Normal sacrum and L4/sacrum.

MATERIALS AND METHODS

The Lumbar vertebra (L4) model is created in (Catia V5 R20 CAD software, Dassault systems Inc., USA) into two sub-parts namely cortical and cancellous bone. Cortical bone is modeled with wall thickness of 1 mm and the remaining region is cancellous bone. Intervertebral discs are found between each vertebra and it is flat and round structures about 6 mm thick. The outer cylindrical portion is annulus fibrosus. Inside of annulus fibrosus a soft, white, jelly like center called nucleus pulposus. Endplate is modelled with the outer profile of vertebral body. The thickness of endplate is 0.5 mm. Sacrum is a large, triangular type bone at the base of the spine. The sacralised modeled in CATIA using solid modelling techniques. The geometric models generated for L4 and sacralised are assembled along with intervertebral disc and the end plate [3]. The meshing has been done using (Hypermesh 13.0, Altair Inc., USA). Using automesh panel 2D trias elements are created for each component and 3D elements, using 'tetramesh' the 2D tria elements are form to tetrahedral elements.

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Table-1. Flow chart.

Step-I
Measurement of Cadaveric bone
Step-II
Generation of the model using CATIA
Step-III
Meshing the model using the Hypermesh
Step-IV
Analysis using the ANSYS
Step-V
Results and Discussion

While transferring 3D elements for tetrahedral elements solid 45 element type is assigned. The meshed model of L4-S1 is shown in Figure-2.The analysis was executed using commercial software (Ansys, ver 14.0, Ansys Inc, USA). The material properties according to literature [2] are assigned to the finite element models. The seven ligaments are created as 'link' elements in ANSYS with corresponding material properties and cross section areas according to literature stated in [2]. The material properties and No. of elements are shown in the Tables 2-5. MASS21 is a point element having up to six degrees of freedom: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. A different mass and rotary inertia may be assigned to each coordinate direction.

Table-2. Material properties of L4-S1.

Contents/Material Properties	Young's modulus (MPa)	Poisson's ratio	Element type
Bone			
Cortical bone (Lumbar L4)	12000	0.3	Solid-45
Cancellous bone (Lumbar L4)	100	0.2	Solid-45
Cortical bone (Sacralised)	12000	0.3	Solid-45
Cancellous bone (Sacralised)	100	0.2	Solid-45

Table-3. Material properties of disc.

Contents/Material Properties	Young's modulus (MPa)	Poisson's ratio	Element type
End plate	12000	0.3	Solid-45
Disc			
Nucleus	0.1	0.499	Solid-45
Annulus	485	0.45	

Table-4. Material properties of ligaments.

Contents/Material Properties	Young's modulus (MPa)	Real constant (Area)	Element type
Anterior Longitudinal Ligament	7.8	24	Link1
Posterior Longitudinal Ligament	10	14.4	
Transverse Ligament	10	3.6	
Ligament Flavum	15	40	
Inter Spinous ligament	10	26	
Supra spinous Ligament	8	23	
Capsular Ligament	7.5	30	

Table-5. No. of elements used in L4 vertebrae and sacralisation.

Components		Nodes	Elements	Element Type
Sacralisation	Cortical bone	95965	393307	Solid45
	Cancellous bone	29055	134638	
L4 vertebra	Cortical bone	20379	70244	
	Cancellous bone	11788	52223	
Disc	Annulus	4867	19263	
	Nucleus	2103	8499	
Vertebral End plate (Top)		2512	7177	
Vertebral End plate (Bottom)		2569	7317	
Element Size		1 mm		

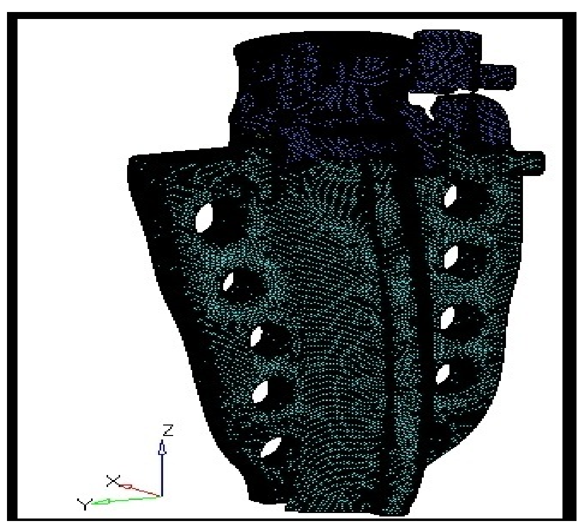

Figure-2. Meshed model of L4/S1.

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Loading and boundary condition

The loading and boundary conditions according to literature [2] are applied to the finite element models. Compressive load of 150 N and a moment of 10 Nm for all physiological motions. Each physiological motion moments are to be applied as mentioned in literatures [2]. To applying moment, a dummy element named 'pilot element' (which has one node) is created in different planes for different physiological motions. The meshed model of L4-S1 is shown in Figure-2.

RESULTS AND DISCUSSIONS

In flexion, range of motion of L4-S1 is calculated as 6.35 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 10 degrees and using the finite element in the literature it is stated as 9.11 degree. In Flexion 30 % reduction of range of motion have been observed when compared to the finite element study stated in the literature. In extension rotation of L4-S1 is calculated as 4.67 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 7.9 degrees and using the finite element in the literature it is stated as 7.33 degree. In extension 36 % reduction of range of motion have been observed when compared to the finite element study stated in the literature [2].In lateral bending left rotation of L4-S1 is calculated as 2.59 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 5.5 degrees and using the finite element in the literature it is stated as 4.95 degree. In lateral bending left 47 % reduction of range of motion have been observed when compared to the finite element study stated in the literature.[2].In lateral bending right rotation of L4-S1 is calculated as 2.57 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 5.9 degrees and using the finite element in the literature it is stated as 5.35 degree. In lateral bending right 51 % reduction of range of motion have been observed when compared to the finite element study stated in the literature [2].In axial rotation of L4-S1 is calculated as 2.61 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 1.8 degrees and using the finite element in the literature it is stated as 2.92 degrees. In axial rotation left 10 % reduction of range of motion have been observed when compared to the finite element study stated in the literature [2]. In axial rotation left 10 % reduction of range of motion have been observed when compared to the finite element study stated in the literature [2].In axial rotation right of L4-S1 is calculated as 2.67 degrees. The L5-S1 under the experimental condition in literature [2] results is stated as 1.5 degrees and using the finite element in the literature it is stated as 3.03 degrees. In axial rotation right 11 % reduction of range of motion have been observed when compared to the finite element study stated in the literature [2].

Table-6. Comparison range of motion with literature.

	Yamanto Experimental (1989)	Li-Xin Guo FEA study (2010).	Current Study
Range of motion (in Degrees)	**L5 and S1 Intact Model**	**L5 and S1 Intact Model**	**L4 and S1 (LSTV)**
Flexion	10	9.11	6.35
Extension	7.9	7.33	4.67
Lateral Bending Left	5.5	4.95	2.59
Lateral Bending Right	5.9	5.35	2.57
Axial Rotation Left	1.8	2.92	2.61
Axial Rotation Right	1.5	3.03	2.67

For the LSTV model, the ROM at the adjacent level L4/S1 is reduced in flexion, lateral bending left, lateral bending right, axial rotation left, and axial rotation right respectively as shown in Figure-3. The ROM in all physiological motion for LSTV is less compared to intact model. The range of motion are reduced as follows in Flexion 30 % is reduced in extension 36 % is reduced in lateral bending left 47 % is reduced lateral bending right 51 % is reduced , axial rotation left 10 % is reduced, and axial rotation right 11 % is reduced as shown in Table-6.

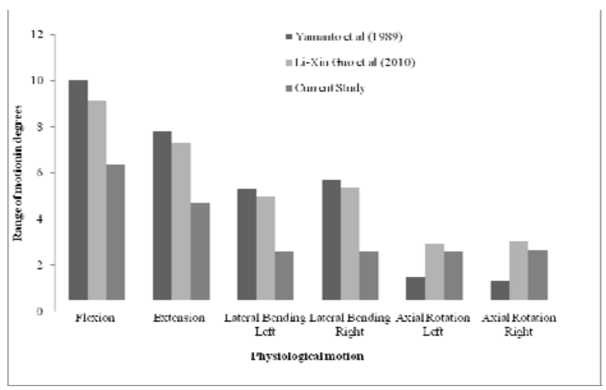

Figure-3. Comparision of RoM L4/S1.

CONCLUSIONS

The FEM study directly compares the L5-Sacrum intact with L4 and sacralised with the input values stated in the literature [2]. This study shows the load distribution and the range of motion in all physiological motions. The physiological range of motion has been decreased in LSTV compared to the intact model. The disc behaviour of L4 and S1 has been observed. This study can be extended for the implant of the artificial disc for LSTV Patients. The patient specific models can be analyzed to predict the range of motion for further treatment. Still Scope is unlimited. The study can be extended to impact loading conditions.

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