

Experimental Analysis of Human Functional Spinal Unit Using AUTOCAD

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ABSTRACT: Ergonomic approach to the Manual Material Handling (MMH) tasks like lifting, pushing, pulling is of interest to the industrial ergonomists. MMH especially, lifting, poses a risk to many and considered as prime cause of back-pains and various other joint impairments. Industrial ergonomists place topmost emphasis on optimisation of posture for safe lifting. In vitro and in vivo studies on real subjects are risky and studies on cadaveric FSU are time consuming. In this paper, we have introduced the Mechanical software A-CAD for design the two dimensional model of Lumbar spine for analysis and predict the stress value during lifting of loads.

KEY WORDS: Lumbar spine, Biomechanical model, A-CAD, Manual Material Handling

I. INTRODUCTION

Biomechanics provides estimation of various mechanical stresses acting on the body while a person manually handles an object. Estimation of stresses imposed on the body musculoskeletal system based on biomechanical model was found to be successful (Maurel et al, 1996). National Institute For Occupational Safety And Health (NIOSH) recognised the problem of work related back injuries and published the Work Practices Guide (WPG) for manual lifting. Actual biomechanical analysis of lifting exertions often require measured values of applied trunk moments and forces as base line for validation data. Accurate measures of the trunk kinetic data are difficult to achieve from dynamic exertions without significant approximation, cost, or motion constraints. It calls for experimental set up by Granata (1996).

Table. 1. Lumbar Spine Properties

Material	Young's Modules (Mpa)	Cross Section Area (mm ²)
Anterior Longitudinal	7.8	63.7
Posterior Longitudinal	10	20.0
Ligamentum Flavum	15	40.0
Transverse	10	3.60
Capsular	705	60.0
Interspinus	10	40.0
Superspinus	8	30.0
Iliolumbar	10	26.4

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II. LITERATURE REVIEW

Many other universities and institutions around the world are producing finite element models of the spine for running various analyses. For example, there are FEMs being created to study the effects of automatic accidents on the spine. The geometry, material properties and loading conditions of the lumbar spine are very complex. Though the FEM is well-established method, various simplifications have to be used and assumptions are to be made (Bowling et al, 1995). The spine is established by muscle forces. In vitro experiments almost never, consider the muscle forces. It is reported that, experimentation has shown that in lordotic spine during prolonged standing, the impacted joints at each segment level bear an average of 16% of the axial load (Oliver, 1991). Hutchinson and Littlefield (Cantau, 1991) tried to simplify FEM of vertebral body by modelling it as a cylinder. This study was conducted to determine the stresses induced in a previously injured spine during pilot ejection. Initially, Hutchinson and Littlefield started FEM by importing data from the DIGIBOT images of the vertebrae into ALGOR V. After an internal mesh was generated by ALGOR V, a PERL script was written to translate the data for ABAQUS to read. The model was then analysed by ABAQUS-Post. The model, having about 30,000 nodes, was too complicated to be processed. As a result of which they have constructed the simplified model. Shirazi-Adl's study (1986) was referenced for the material properties of the lumbar region. The empirical quantities of the spinal components used in shirazi-Adl's study are shown in Table 3.1. Work on FEM analysis of segmental level lumbar L2/L3 and cervical spine (Carlos, 2000; Lian, 2000) were found during the survey. But, the combined L1/L2/L3/L4/L5/S1 (FSU) FEM analyses have not been found to have been done.

III. DESIGN AND ANALYSIS OF FUNCTIONAL SPINAL UNIT (FSU)

Manual Material Handling (MMH) activities, lifting is considered to be a major cause for low back pain and spinal injuries. Annual costs associated with back pain in US alone ranged from 20 billion US\$ to 50 billion US\$ (Miller, 1997). Although epidemiological studies have suggested possible causes, the actual mechanisms by which the lumbar spine is injured during load cycle resulting in low back pain, remains unknown. However, the response of the disc to loading conditions that occur during lifting is difficult to measure in vivo and in vitro and has not been investigated using any model (Williams, 2002). In vitro and in vivo studies on real subjects are risky and studies on cadaveric FSU are time consuming. Here, an attempt has been made to analyse FSU using suitable finite element modelling for sagittal plane lifting activity. Spinal unit, otherwise known as vertebral column consists of 24 separate bony vertebrae together with 5 fused vertebrae, which form the sacrum, and usually 4 fused vertebrae, which form the coccyx, 24 separate vertebrae are interlaced with inter-vertebral discs. Normally the column appears symmetrical in the frontal plane and has characteristic curvatures in the sagittal plane. Curvatures provide natural shock absorbency and flexibility (Fig 1). Three principal functions of vertebral column are to

1. Support the human in the upright posture
2. Allow moment and locomotion
3. Protect the spinal cord.

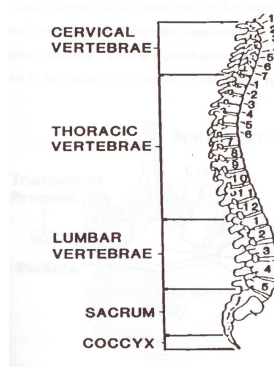


Fig 1. The spine and Lumbar Spine

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IV. TWO DIMENSIONAL MODELLING

2D modelling is the modelling of a continuous system, which has a infinite number of degrees of freedom, using a representative geometry of that system made up of a finite number of smaller elements and node points. The more elements in the model, the more accurate it is. The material properties, displacements, and other system characteristics are represented by mathematical functions between nodes. This finite element model can then be used to determine the stress, strain, and displacement of the structure resulting from external loading (Cantau, 1997). Once the Finite Element Model has been created and the system characteristics have been established in the model, a global stiffness matrix can then be formed for the whole structure. Given the forces and boundary conditions, the unknown displacements at each of the node points can then be used to determine the stresses and strains acting on each element (Cantau et al., 1997). Initially, the Finite Element Models were applied to aircraft structures, and then FEM rapidly spread to Civil Engineering and Mechanical Engineering. FEM is gaining acceptance as a valuable tool to study static, dynamic as well as cyclic problems. Only recently FEM has been seriously applied biomechanical problems.

ANTHROPOMETRY OF FSU

Functional Spinal Unit (FSU) consists of Lumbar and sacrum region. Lumbar vertebral column comprises of five vertebrae and the intervertebral discs. It has a characteristic curvature called lumbar Lordosis. In the standing position, the sacrum is tilted forwards so that its upper surface is inclined forwards and downwards forming an angle between the top of the sacrum and the horizontal, which varies between 50° – 53°

FACTORS CONTRIBUTING TO THE NORMAL SHAPE OF THE LUMBAR LORDOSIS

The common factors that maintain the normal shape of the lumbar lordosis are listed below:

1. L5 vertebral body is wedge shaped, the anterior body wall is 3 mm higher than the posterior body wall. This brings the upper surface of the L5 body closer to the horizontal plane than the upper surface of the sacrum
2. In addition, the L5/S1 disc is also wedge shaped, the anterior vertical height is 6~7 mm greater than its posterior height. As a result of the wedge shape of the disc, the lower surface of the vertebral body is not parallel to the upper surface of the sacrum, so that the angle formed between the two surfaces may vary between 6° ~ 29° and has an average size of 16° .
3. Each vertebra above is inclined slightly backwards in relation to the vertebrae below.
4. In 75% of the adults the center of gravity lies anterior to the vertebral column. In these individuals there is constant activity in the erector spine muscles, which work to prevent the trunk from falling forwards and assist in maintaining the lumbar lordosis.
5. In a normal spine, in the upright posture, the body of L5 lies directly vertically above the sacrum. Various attempts have been made to measure the lordosis, but as investigators have used different parameters the result differ substantially.

ASSUMPTIONS

Following assumptions were made while modelling FSU:

1. Vertebrae were considered as having elliptical cross section. Actually this is an improvement over Hutchinson-Littlefield model. Ellipse gives a closer approximation.
2. Upright standing posture is assumed for modelling.

V. MODELLING AND ANALYSIS OF FSU

With the advent of Magnetic resonance imaging (MRI), one can measure internal organs and bones with high resolution and accuracy. MRI is a non-invasive imaging approach. Cross sectional size of L1 lumbar vertebra were measured from an adult subject using MRI scan. It is found to be 40mm Major and 32 mm minor. Based on the anthropometric proportions, other dimensions were arrived at. There are host of software for 3D modelling and here Pro/Engineer is preferred because of its simplicity and seamless integration with analysis package Pro/ Mechanical.

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Whole FSU were modelled in parts and assembled according to the configuration as shown in Fig 2. Assembled model was transferred to Pro/Mechanica environment.

BOUNDARY CONDITIONS

Lower vertebral disc (L5/S1) of the L5 body was fixed. All other vertebral bodies and discs were allowed all degrees of freedom. Loading according to literature, lumbar vertebrae L1 share only 11% of axial load, leaving the rest of the load of muscles. This was taken in to consideration while loading the FE model. Axial force due to body weight is calculated (at L5/S1) as following:

From forces along spine direction

$$F - ES - B \cos \theta - W \cos \theta = 0 \quad \text{----- 1}$$

Moment:

$$ES \times l = Bb + Ww \quad \text{----- 2}$$

From forces along spine direction (For lifting 10Kg load)

$$ES \times 0.06 = (400 \times 0.18) + (98 \times 0.35)$$

$$ES = \frac{72 + 34.3}{0.06} = 1771.5 = 1772$$

Substituting the ES value in equation 1.

$$F - 1772 - 400 \cos 52^\circ - 98 \cos 52^\circ = 0$$

$$F - 1772 - 306.6 = 0$$

$$F = 2079 \text{ N}$$

Where

$$\theta = 52^\circ$$

Axial force on L1 is 228 N @ 11 %

Load was applied on L1 top surface. Refer Fig 2 Pro/Mechanica's AutoGEM created elements and meshes. Solver was run to get the results with 2% p-loop convergence. Fig 2 shows the deformation of the model for lifting a load of 10Kg. Calculations are as shown below: Maximum vonmises stresses are found at L5/S1 and L4/L5 and it's magnitude found to be 3.05 Mpa.

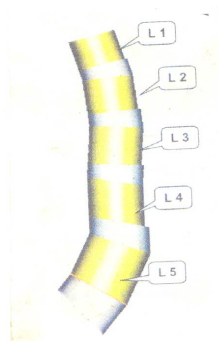


Fig.2. 2D Model FSU Assembly

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VI. CONCLUSION

The model assembly of the FSU of this study was done using PRO/E. FSU assembly model is shown in Fig 2. As it was mentioned, the model was first generated for upright position with only body weight condition. The normal posture of the FSU was emulated to the reality. The segments from L1 through L5 were modelled for a normal adult. Fig 24.5 shows the Finite Element Model of the FSU under loaded condition and the constraints. The deformation of the model, under the load of 10Kg and boundary condition, is depicted. Maximum Von Mises stress was found at L5/S1 and at L4/L5 and its magnitude was found to be 3.063MPa.

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