Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 6, No. 3, PP 85 - 91 (2010)

The Stress Distribution on the Zygapophyseal Joint of Lumbar Vertebra by ANSYS Program

Akram A. Jaffar *   Sadiq J. Abass   Summer S. M. Mukhtar****

** Department of Human Anatomy/ College of Medicine/ University of Al-Nahrain*

*** Department of Medical Engineering/ College of Engineering/ University of Al-Nahrain*

(Received 23 May 2007; Accepted 22 September 2010)

Abstract

Zygapophyseal joints (or facet joints), are a plane synovial joint which located between the articular facet processes of the vertebral arch which is freely guided movable joints. Ten dried vertebrae were used for the lumbar region and taking (L_4) as a sample to reveal stress pathways across the joints by using ANSYS program under different loading conditions which used Finite Elements Analysis model. Results obtained from the ANSYS program are important in understanding the boundary conditions for load analysis and the points of stress concentration which explained from the anatomical point of view and linked to muscle and ligament attachments. This model used as a computational tool to joint biomechanics and to prosthetic implant analysis.

Keywords: *Spine, zygapophyseal joint, vertebra, biomechanical properties.*

1. Introduction

The functional unit of the vertebral column consists of two adjacent vertebral bodies, an intervertebral disc and two zygapophyseal joints. This unit is called motion segment. The size and angulations of the vertebral processes vary throughout the spinal column. This changes the orientation of the facet joints, which limit range of motion in the different spinal regions. The facet joints and discs provide about 80% of the spine's ability to resist rotational torsion and shear, with half of this contribution from the facet joints. The facet joints also sustain up to approximately 30% of the compressive load on the spine, particularly when the spine is in hyperextension (1995) [1].

Kim-Kheng Lee et al. (2002) [2], study a three-dimensional geometrical and mechanical accurate finite element model of human lumbar spine (L_2/L_3) was developed from 3D geometrical data of embalmed lumbar spine (L_2/L_3) obtained using a highly accurate touch-probe digitizer. The methodology developed for the 3D digitizing process provides an alternative method in capturing the highly irregular bony structure of spine as compared to commonly used CT scan image by other investigators. Having a realistic and validated mathematical model of the spine would further establish itself a useful adjunct to the experimental approaches for investigating clinical problems of the spine and may be used to predict biomechanical responses of the spine under physiological and trauma loadings.

Mohammad H. Kargarnovin et al. (2005) [3], in his study, primarily by employing the CT scan technique the image of an actual (L_4-Disc-L_5) motion segment of the lumbar spine is constructed. In the next step, these images are transferred to an AutoCAD environment and each surface is divided into number of rectangles. These rectangles on parallel adjacent planes were joined together to comprise the eight nodded brick type finite elements. When these finite elements are formed throughout the media, then stress analysis is carried out. Results obtained from this model are compared with results of other investigators, where good agreements are observed. Moreover, the developed one segment model of (L_3-disc-L_4) is used to model the two segments model of (L_3-disc-L_4-disc-L_5).

The lumbar vertebrae are much stouter and stronger than those in either the thoracic or cervical regions. The Lumber articular processes project upwards and downwards from the region where the pedicle joins the lamina. The articular facets on the superior process are concave transversely and flat vertically, facing posteromedially. The inferior articular processes are set closer together than the superior and have facets which are reciprocally curved to face anterolaterally (1998) [4].

Mechanical forces acting on the vertebrae are; tension force, compression force, shears force and torque. In the spine, the ligaments are loaded in tension. Tensile forces also occur in the intervertebral disc during the rotational movements of flexion, extension, axial rotation, and lateral flexion (Fig.1). The nucleus tends to bear the compressive load, and the annular fibers tend to bear the tensile loads (1992) [5].

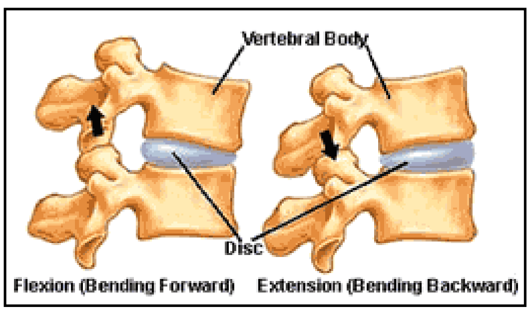


Fig.1. The intervertebral Disc and Facet Joint During Flexion-Extension Movement.

Compressive loads applied in flexion tend to cause anterior collapse of the endplate or vertebral body, where the bony structure is weaker. With compressive loads applied in extension, a significant percentage of the compressive load is transmitted through the facets, leading to capsular injuries (2005) [6]. Living things are also subjected to shear forces, the facet joints and the fibers of the annulus fibrosus resist shear forces in the spinal motion segment. Under normal physiologic conditions, the facets can resist shear forces when they are in contact. If, however, the disc space is narrowed by degeneration with subsequent thinning of the disc, abnormally high stresses may be placed on the facet joints, and the limit of resistance to such forces is not well documented (1992) [7]. In a curved structure, such as the spine, bending also occurs when a torque load is applied.

Adams and Hutton disagreed demonstrated that primarily the facets resist the torsion of the lumbar spine and that the compressed facet was the first structure to yield at the limit of torsion. Others have performed experiments that further suggest and support that the posterior elements of the spine, including the facet joints and ligaments, play a significant role in resisting torsion (1981) [8].

2. Experimental Method

ANSYS finite element analysis software enables engineers to perform the important task; do prototype testing in environments where it otherwise would be difficult or nonlinear in geometry (for example, biomedical applications).

The first step in ANSYS programs is the model generation. In this study, importing a model created in a computer-aided design (CAD) system (geometry of L_4 vertebra built in AutoCAD program) (2005) [9].

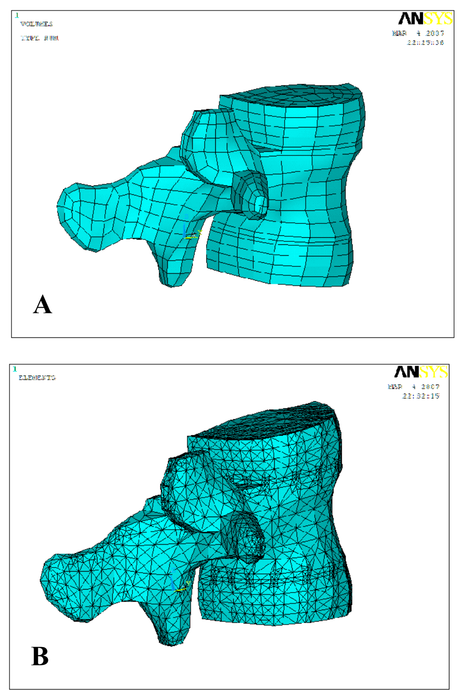


Fig.2. A) ANSYS Show the Volume of Lumbar Model (L_4), Side View. B) ANSYS Show the Meshing of Lumbar Model (L_4), Side View.

The model imported to the ANSYS as IGES file which is consist numbers of areas, then these area converted to number of volumes as show in Fig.(2a).

Available element type was chosen linear order element (Solid/Brick 8node 45) and the analysis type is static (study-state) see Fig. (2b).

The materials properties taking as linear elastic isotropic materials with (ν=0.3 & E=9 GPa) (2002) [10].

The body weight and displacement consider as a boundary conditions Fig. (3). Displacement at z = 0, because the model is symmetry. Percentage of the body weight on the $L_4 \approx 54\%$ (1990) [11].

The boundary forces of lumbar model are represented by muscles and ligament forces attached to the bone in addition to the body weight Fig. (4). the basic equation of moment equilibrium was used to calculate these forces.

$$\Sigma M_O = 0 \quad \ldots(1)$$

where O is the center of rotation.

The muscle forces activate on the lumbar vertebrae (L_4) during static position as follows in Table (1) (1996) [12].

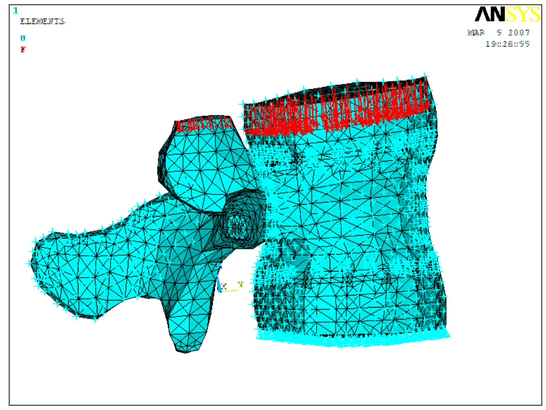


Fig.3. ANSYS Show the Boundary Conditions of Lumbar Model (L_4).

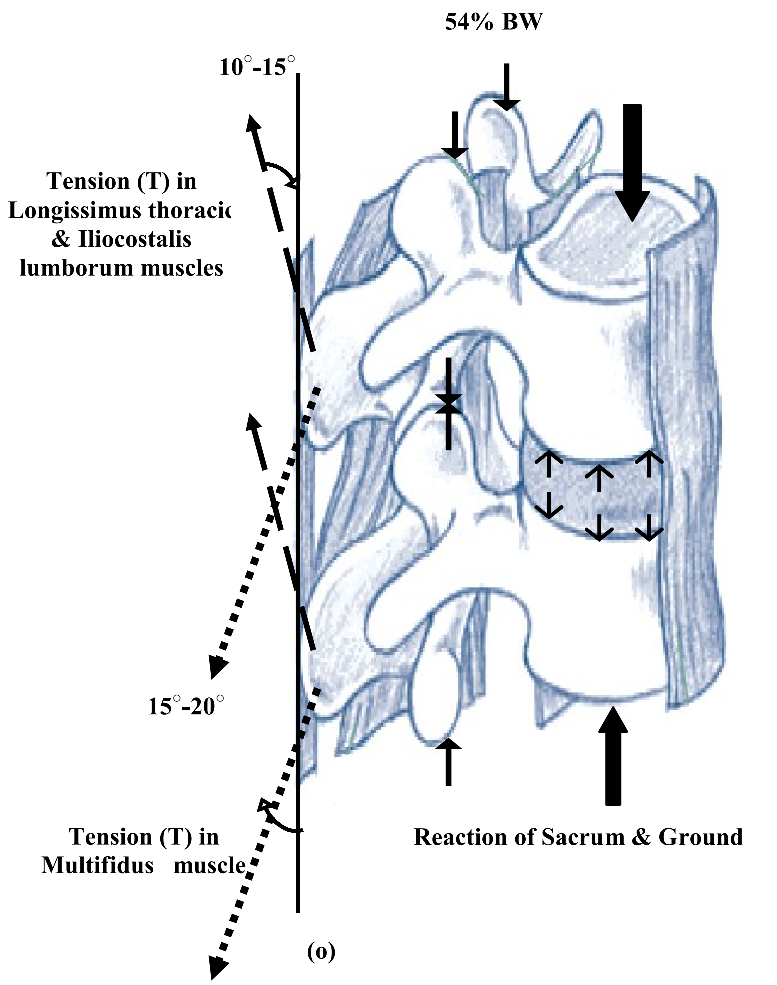


Fig.4. Free Body Diagram for Lumbar Vertebrae with Muscle Attachments

Table 1,
The Calculated Muscle Forces Acting on (L_4) Vertebrae. LT: LONGISSMUS Thoracic. IC: Iliocostalis Lumborum. MF: Multifidus. QL: Quadratus Lumborum (1996) [12].

Body weight (kg)	54% Body weight on L_4 vertebrae (N)	LT (N)	IC (N)	MF (N)
75	397.30	0.024	0.062	0.187
100	529.74	0.032	0.083	0.249
125	662.17	0.040	0.104	0.312

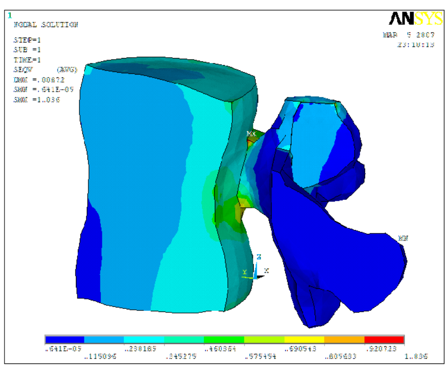
3. Result Description

There are a lot of methods for results description, but we used the (Contour values).This technique uses the eight color codes to represent the results. The contours colors represent the range of the stresses, from the low value to the high value.

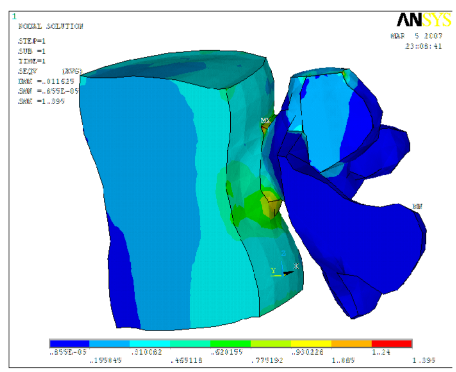
Chose the three body weights (75kg, 100kg, and 125kg) to describe the applied forces on the lumbar model (L_4) as follows in Table (2). The stress results were represented as a Von Mises stress in Fig.(5a, 5b, 5c).

Table 2,
Summary of Von Mises Stress of L_4.

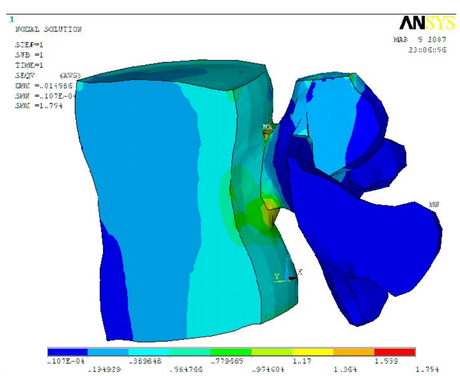
Regions	Von Mises Stress (MPa)		
	75kg	100kg	125kg
The facet surface	0.179	0.265	0.515
Edges of the facet area	0.233	0.435	0.870
Superior surface of the body	0.292	0.398	0.678
Posterior surface of the body	0.451	0.615	0.754
Upper surface of the pedicle	0.687	0.924	1.082
Lower surface of the pedicle	0.695	0.959	1.237



A



B



C

Fig.5. A) Von Mises Stress for 75kg Body Weight of the Medial View of L_4. B) Von Mises Stress for 100kg Body Weight of the Medial View of L_4. C) Von Mises Stress for 125kg Body Weight of the Medial View of L_4.

4. Discussion

Over the years, mathematical modeling (such as finite element method) has established as a complementary to experimental approach in investigating clinical problems of the spine as well as predicting the biomechanical behavior (2002, 1995) [2, 13]. Common method used for mesh geometry by investigators is by stacking coronal and sagittal computed tomography (CT) images sequentially to develop and discrete the 3D solid model. With this method, the finite element model could not well represent the geometry of the highly irregular vertebra, especially its posterior element (2002, 2001) [2, 14]. Using CAD system to import the spine geometry into finite elements model, was improved the mesh quality as compared to the model created from CT images (1995) [13].

Because the load transmitting from the cervical region to the lumbar region; so, the lumbar vertebrae supporting the maximum load and body weight (2001) [15]. Some of the verifications for the lumbar vertebrae in the journals was concentrated on L_5 but in our analysis taken L_4 as a sample to apply the model analysis and to know more biomechanical application about L_4 (1992, 1990) [7, 11].

The analytic result underscores the role of disc as major compression-carrying component of the spine with the remaining portion supported by the facet (2002) [2]. The results noticed that the maximum von mises stress on the surface of the posterior elements joints means the area with high normal stress (σ) and shear stress (τ). While the area of the extreme superior vertebral body surface and the facet surface noticed that minimum von mises stress occur by the compression stress (2005, 2000) [16, 17].

In normal upright posture, the lumbar spine curves backwards. The vertebrae are therefore situated at angles to the horizontal, and gravity not only causes a compressive axial force along the spine, but also induces a shear force wanting to pull the vertebrae forward over each other. Compressive forces are shared by the vertebral bodies and intervertebral discs, and shear forces are shared by the discs and spinal ligaments. It has been estimated that the posterior elements carry approximately 16% of the total load when a person is standing upright (1997) [18].

The facets and other posterior elements have a load-bearing function to help support the weight of the upper body and anything that it carries, and are also acted upon by spinal muscle forces. The facet load is the main force acting on the neural arch (1998) [19]. Loading of the inferior articular process and bending in the pars cause high stresses because the pars is the narrowest part of the neural arch, i.e., has the smallest cross-sectional area with which to resist load (2000) [17].

The vertebral body of the lumbar spine expose to more applied compressive force which is the maximum stress was shifted from the centre to the posterior position. The stresses in the core then decrease, with the shell absorbing larger loads (2005) [3]. The tendency of L_4 and L_5 to be the most susceptible to fractures is due in part to the fact that they are so low in the spine and therefore must carry more loads from the upper body than vertebrae higher up (1997) [18].

The modelling of the complex facet geometry and proposed algorithm for articulation has resulted in good agreement with reported results (2005, 1981) [3, 8] and would be interesting to extend it to other loadings for which the facets play a more active role in restraining the motion and transferring the load. Realistic clinical-related cases pertaining to facet joints would thus be able to achieve with the accurate representation of the facet geometry and articulation algorithm built into the FE model (2002) [2].

The vertebral body of the lumbar spine appears as the same level with vertebral arch in the ANSYS program, in addition to narrow the vertebral body in model analysis. Because the geometry of the posterior element of the vertebra is very difficult when build by AutoCAD system.

In our model, the vertebra was irregular symmetric geometry for this reason used half lumbar vertebra (which take RAM 2GB memory size with CentrinoDuo processor) in stress analysis in addition to this reason, the whole shape of the vertebra takes RAM 4GB memory size or more and higher processor (used advance computers or expensive full option laptops).

5. Conclusion

- The geometry build by any CAD system, is the easier method than old CT system (6, 10, 16 slice) to create any irregular shape like lumbar vertebrae, then imported to the ANSYS program to give precise results.
- The new models of CT system (32, 64, 128, 256 slice) which have the 3D options can uses in future work to build the complex irregular shapes (like the vertebra).

- Although the advanced system give high accuracy in application but not used in our model analysis because very expensive.
- The results from von mises stress demonstrated the articular facet joint shared in 15-20% from body weight and support the vertebral body during compression load.

6. References

[1] Hall Susan J., Basic Biomechanics. 2nd Edition, McGraw-Hill Companies. 1995; 252-269.

[2] Kim-Kheng Lee, Tian-Xia, Qiu, and Ee-Chon Teo, 3D Finite Element Modeling of Lumbar Spine (L2/L3) Using Digitizer, International Journal of Information Technology, 2002; 8(2):1-9.

[3] Kargarnoviun Mohammad H., Moayyed Ali A., and Ghate Azar, Stress Analysis on Anterior Fixator (TSRH) of Lumbar Spine, Int. J. Sci. Res., 2005;15: x-y.

[4] Palastanga N., Filed D., and Soames R., Anatomy & Human Movement: Structure & Function, 3rd Edition, Butterworth Heinemann. Boston. 1998:579-704.

[5] Andersson GBJ, Biomechanics of the lumbar spine: Managing low back pain, 3 rd Edition, New York, 1992, Churchill Livingstone.

[6] Michelson T., Posterior Lumbar Interbody Fusion, Medtronic Sofamor Danek, 2005:53.

[7] Garg A, Occupational biomechanics and low back pain, Occupational Medicine, State of the Art Reviews, 1992; 7(4):609.

[8] Adams MA, Hutton WC, The relevance of torsion to the mechanical derangement of the lumbar spine, Spine, 1981; 6:241.

[9] ANSYS ® V.10 Package (2005) Help.

[10] Homminga J, McCreadie BR, Ciarelli TE, Weinans H, Goldstein SA, and Huiskes R., Cancellous bone mechanical properties from normals and patients with hip fractures differ on the structure level, not on the bone hard tissue level, Bone, 2002;30(5):759-64.

[11] White, A. A. and Panjabi, M. M., Clinical Biomechanics of the Spine. Philadelphia, J.B. Lippincott Co., 1990: 315-326.

[12] Shirazi-Adl A., Parnianpour M., and Sadouk S., On Evaluation of Muscle Forces and Spinal Passive-Active Synergy in Compression, Journal Biomech. Eng., 1996; 118: 26-31.

[13] Goel VK and Gilertson LG, Application of the finite element method to thoracolumbar spinal research – Past, Present, and Future, Spine, 1995; 20:1719-1727.

[14] Yoganandan N, Kumaresan S and Pintar FA, Biomechanics of the cervical spine Part 2: Cervical spine soft tissue responses and biomechanical loading, Clinical Biomechanics, 2001; 16:1-27.

[15] Pal GP and Routal RV, The orientation of articular facets of the zygapophyseal joints at the cervical and upper thoracic region, Journal of Anatomy, 2001; 198: 431-441.

[16] Kargarnoviun Mohammad H., Moayyed Ali A., and Ghate Azar, Stress Analysis on Anterior Fixator (TSRH) of Lumbar Spine, Int. J. Sci. Res., 2005;15: x-y.

[17] Klemenesics, Z.L. and Kiss, R.M., The biomechanics of spondylolysis, 22nd Edition Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Piscataway, 2000.

[18] Gatt C.J., Hosea T.M., Palumbo R.C, and Zawadsky J.P., Impact Loading of the Lumbar Spine During Football Blocking, The American Journal of Sports Medicine, 1997; 25(3): 317-321.

[19] Inoue, H., Ohmori, K., Ishida, Y., Finite Element Analysis of the Lower Lumbar Neural Arch Under Facet Loading, Journal of Spinal Disorders, 1998; 11(3): 241-247.

توزيع الأجهاد على مفصل النامية المقرنية للفقرة القطنية من قبل برنامج ANSYS

اكرم عبود جعفر* صادق جعفر عباس** سمر سرمد محمود مختار**
* قسم التشريح البشري/ كلية الطب/ جامعة النهرين
** قسم الهندسة الطبية/ كلية الهندسة/ جامعة النهرين

الخلاصة

مفاصل النامية المقرنية او (مفاصل الظهر) هو مفصل زلالي مستوي يحدد مكانه بين نتوءات المظهر المفصلية للتقوس الفقري وهي عبارة عن مفاصل متحركة بحرية. استعملت عشر فقرات مجففة للمنطقة القطنية واخذت (الفقرة القطنية الرابعة) كعينة لكشف ممرات الأجهاد عبر المفاصل بأستعمال برنامج ANSYS تحت شروط التحميل المختلفة والتي استعملت لها نموذج تحليل العناصر المحدود. النتائج التي حصلت من برنامج ANSYS مهم في فهم الشروط الحدية لتحليل الحمل ونقاط تركيز الأجهاد الذي وضحا من وجهة النظر التشريحية والاتباط العضلات والأربطة المتصلة. هذا النموذج استعمل كاداة حسابية لربط علم الميكانيك الحيوي مع تحليل الزرع البديلي.