UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

BIOMECHANICAL STUDY OF HUMAN LUMBAR SPINE WITH TOTAL DISC REPLACEMENT OF MAVERICK® PROSTHESIS USING FEM

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Master of Science in Mechanical Engineering

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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2015

DECLARATION

I declare that this thesis entitle "Biomechanical Study of Human Lumbar Spine with Total Disc Replacement of Maverick® Prosthesis Using FEM" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : Siti Nurfaezah binti Zahari

Date : .....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering.

Signature : .....

Supervisor Name : Mohd Juzaila bin Abd. Latif

Date : .....

DEDICATION

To my beloved mother and father

ABSTRACT

Obesity is one of the concerns that could cause low back pain. Excessive load on the spine could change the mechanical behaviour of the lumbar spine and affected on the pressure and stress that occurs in the intervertebral disc particularly at nucleus pulposus and annulus fibrosus. However, the biomechanical effects of body weight on the lumbar spine and implanted lumbar spine are yet to be fully understood. Thus, the aim of this study was to investigate the biomechanical effects of body weight on the lumbar spine as well as adjacent segments of the implanted lumbar spine. Three dimensional finite element model of the osseoligamentous lumbar spine and implanted lumbar spine models was developed and verified with previous studies. The finite element model was subjected to follower compression load of 500 N, 800 N and 1200 N to represent the load case of normal, overweight and obese with a combination of pure moments of 7.5 Nm in flexion and extension. Increasing weight shows significant effect on the kinematics of the lumbar spine for both finite element models. The excessive load on the lumbar spine increased the pressure and stress that occurs in the intervertebral disc, particularly at the nucleus pulposus and annulus fibrosus. The nucleus pressure was higher in flexion and increased as the compressive load was increased. This phenomenon could contributes to the earliest stages of disc degeneration which occurs in the nucleus pulposus. However, increasing weight were more severe in extension as its results in increased the annulus stress, particularly at posterior intervertebral disc up to 17%. Besides, the increasing weight on the implanted lumbar spine also has the potential to alter the movement of the lumbar spine during flexion and extension motions. The presence of a higher weight applied on the implanted lumbar spine and rigidity of Maverick prosthesis at the operated segment of L4-L5 was suggested as a contributing factor to accelerate in changing the kinematics of the implanted lumbar spine. The changes in kinematics of the implanted lumbar spine gave significant effect on the nucleus pressure and annulus stress. Its results in increased the nucleus pressure up to 155% and 124% in annulus stress compared with the non-implanted lumbar spine which observed in the region of L3-L4 lumbar segment. The high stress on the annulus particularly at the posterior of the disc could accelerate annular tear at the disc rim. In conclusion, flexion and extension appears to have differing affects to disc structure. Whilst flexion increases the nucleus pressure, extension results in the increase in the annulus stress. Heavier individuals are expected to experience an increase in stress and pressure of the disc regardless of the position of the spine. Therefore, an increase in body weight of the lumbar spines changed the kinematics of the lumbar spine and causes an increase in the nucleus pressure and annulus stress. This may be a factor that can lead to early intervertebral disc damage particularly at disc rim. Besides, an increase in body weight of the implanted lumbar spine can also expedite the tendency of disc degeneration at adjacent segments and may require additional surgery.

ABSTRAK

Obesiti adalah salah satu masalah yang boleh menyebabkan sakit di bahagian tulang belakang. Beban yang dikenakan pada tulang belakang boleh mengubah tindak balas mekanikal tulang belakang dan menjejaskan tekanan kepada cekera intervertebral terutamanya pada nukleus pulposus dan anulus fibrosus. Walau bagaimanapun, kesan berat badan pada tulang belakang lumbar dan tulang belakang lumbar yang di masukkan implan secara biomekanik masih belum difahami sepenuhnya. Oleh itu, tujuan kajian ini dibuat adalah untuk mengkaji kesan biomekanik berat badan pada tulang belakang lumbar dan juga segmen-segmen yang terletak bersebelahan dengan segmen yang dimasukkan implan.Tiga dimensi model unsur terhingga tulang belakang lumbar yang lengkap dengan ligamen-ligamen dan juga tiga dimensi model unsur terhingga tulang belakang yang dimasukkan implan dibangunkan dan disahkan dengan kajian sebelum ini. Beban mampatan secara ikutan iaitu 500 N, 800 N dan 1200 N dikenakan kepada model-model unsur terhingga untuk mewakili kes beban berat badan yang normal, berlebihan dan obes, dengan gabungan momen tulen sebanyak 7.5 Nm dalam akhiran dan lanjutan. Peningkatan berat badan telah menunjukkan kesan yang ketara ke atas kinematik tulang belakang lumbar untuk kedua-dua model tiga dimensi unsur terhingga. Beban yang berlebihan pada tulang belakang lumbar meningkatkan tekanan yang berlaku dalam cakera intervertebral terutamanya di nukleus pulposus dan anulus fibrosus. Tekanan nukleus adalah lebih tinggi pada pergerakan akhiran dan meningkat apabila beban mampatan yang dikenakan meningkat. Fenomena ini boleh menyebabkan berlakunya kemerosotan pada cakera di peringkat paling awal di mana ianya berlaku pada nukleus. Walau bagaimanapun, peningkatan berat badan adalah lebih teruk dalam pergerakan lanjutan kerana ianya telah menyebabkan peningkatan pada tekanan di annulus terutamanya di bahagian belakang cakera sehingga 17%. Selain itu, berat badan yang meningkat juga mempunyai potensi untuk mengubah pergerakan tulang belakang lumbar semasa pergerakan akhiran dan lanjutan selepas pembedahan penggantian cakera. Kehadiran berat badan yang lebih tinggi dan ketegaran pergerakan daripada implan "Maverick" yang dimasukkan di segmen L4-L5 segmen lumbar telah dicadangkan sebagai satu faktor yang menyumbang kepada mempercepatkan dalam mengubah kinematik tulang belakang lumbar yang dimasukkan implan. Perubahan dalam kinematik tulang belakang lumbar yang dimasukkan implan memberi kesan yang besar ke atas tekanan nukleus dan tekanan anulus. Keputusan dalam peningkatan tekanan nukleus adalah sehingga 155% dan 124% dalam tekanan anulus berbanding dengan tulang belakang lumbar yang tidak

dimasukkan implan dimana ianya diperhatikan di segmen lumbar L3-L4. Tekanan tinggi pada anulus terutamanya di belakang cakera boleh mempercepatkan koyakan anulus di tepi cakera. Kesimpulannya, kesan struktur cakera yang berbeza yang ditunjukkan pada pergerakan akhiran dan lanjutan. Pergerakan lanjutan meningkatkan tekanan pada anulus, manakala pergerakan akhiran meningkatkan tekanan pada nukleus,. Individu yang lebih berat dijangka akan mengalami peningkatan dalam tekanan pada cakera tanpa mengira kedudukan tulang belakang. Oleh itu, kenaikan berat badan pada tulang belakang lumbar telah mengubah kinematik tulang belakang lumbar dan ini menyebabkan peningkatan tekanan nukleus dan tekanan anulus. Ini boleh menjadi faktor yang membawa kepada kerosakan awal pada cakera intervertebral terutamanya pada rim cakera. Peningkatan berat badan pada lumbar tulang belakang yang diimplan juga boleh mempercepatkan kecenderungan kepada degenerasi cakera di segmen-segmen bersebelahan dan boleh memerlukan pembedahan tambahan.

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LIST OF ABBREVIATIONS

LBP	-	Low back pain
TDR	-	Total disc replacement
DDD	-	Degenerative disc disease
FE	-	Finite element
FEM	-	Finite element method
FEA	-	Finite element analysis
ROM	-	Range of motion
IDP	-	Intradiscal pressure
VMS	-	Von Mises stress
L1	-	The first lumbar vertebra
L2	-	The second lumbar vertebra
L3	-	The third lumbar vertebra
L4	-	The fourth lumbar vertebra
L5	-	The fifth lumbar vertebra
IVD	-	Intervertebral disc
ISR	-	Instantaneous centre rotation
FSU	-	Functional spinal unit
PLL	-	Posterior longitudinal ligament
ALL	-	Anterior longitudinal ligament

LF	-	Ligamentum flavum
CL	-	Capsular ligament
ITL	-	Intertransverse ligament
ISL	-	Interspinous ligament
SSL	-	Supraspinous ligament
VLe	-	Ventral-lateral external
VLi	-	Ventral-lateral internal
De	-	Dorsal external
Di	-	Dorsal internal

LIST OF SYMBOLS

F	-	Force
ν	-	Poisson's ratio
E	-	Young's modulus
ε	-	Strain
C_1, C_2	-	Material constant characterising the deviataric deformation of material
R	-	Radius
L	-	Length
θ	-	Theta
®	-	Copyright

LIST OF PUBLICATION

A. Conference

1) Zahari, S.N, Abd Latif, M.J., & Kadir M.R.A. (2014).”The Influence of Preload Application for Vertebra Segment in Finite Element Modelling”, 2014 IEEE EMBS Conference on Biomedical Engineering & Sciences (IECBES 2014), Miri, Malaysia, 8th December – 11th December 2014. IEEE Explore Publisher.