UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

THE BIOMECHANICAL EFFECT OF HUMAN WEIGHT ON SPINAL FACET JOINTS USING FINITE ELEMENT ANALYSIS

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A dissertation submitted
in fulfillment of the requirements for the degree of Master of Mechanical Engineering
(Applied Mechanics)

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DECLARATION

I declare that this dissertation entitles "The Biomechanical Effect Of Human Weight On Spinal Facet Joints Using Finite Element Analysis" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : Raed Ali Mohammad..

Date: : ....4/7/2016.......................................

APPROVAL

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

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Date: : 01/08/2016 ....

DEDICATION

This dissertation work is dedicated to my Parents; My father (Ali Mohammad), you have always been an inspiration to me, you set a great example for me, when I think back of the sacrifices you made then I know that you gave most precious gift for me.

My mother, who put up with me for all these years. Throughout the years, you've always been by my side; I can face anything with you by my side.

My wife, who has supported and encouraged me, you're so creative. You give a lot, and i appreciate how much you give.

For my sons; Bahaa, Akram, Hussam, Bassam, my brother and sister, and my big family, i ask "Allah" to protect you all; you are good examples have taught me to work hard for the things that I aspire to achieve.

ABSTRACT

Many important medical associations define obesity as a disease. Being overweight or obese is a serious disorder that affects human spine. Obesity is a contributing factor to back pain due to changing for the mechanical properties as a result to the over loading. Hence, being overweight or obese can significantly contribute to symptoms associated with osteoarthritis (OA), facet joint arthritis, degenerative disc disease (DDD), spinal stenosis, and spondylolisthesis. However, the facet joint behavior regarding the body weight effects under separate loadings or the responses to the compressive loads in the discs need to be identified. Moreover, using cadaveric specimens in biomechanics testing of the lumbar spine restricted with a difficulty in acquiring the disc pressure, bone strain and facet joint contact pressure. While, simulation model looks into all of these disadvantages. Thus, the goal of the current study was to develop a method to simulate the biomechanics of the lumbar spine, and to delve into the effect of obesity on the intervertebral discs and facet joint in addition to provide the system analysis of the spine between multi body weights. The finite element analysis results will highlight significant differences if the model adopted is performed under different material properties, geometries, loading modes or other conditions. A process is currently in use to transform a CT scan of a lumbar spine into a simulation model. The process includes changing the CT scan to a geometry file and creating a mesh of the bone and soft tissue, and assigning material properties to each bone element based on the bone density. 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. The results highlight the fact that in all loadings case of (normal, overweight and obese people), there are high distributions of stress in both L4 and L5 and so on the intervertebral discs. Increasing the human weight was in turn increasing the nucleus pulposus pressures and annulus fibrosus stresses. Intradiscal pressures in the nucleus pulposus were increased more noticeably with flexion than with extension. With regard to the facet joint forces, flexion resulted in a larger facet force in the superior facet joints than that in the inferior facet joints at the same level and in extension was 21% more than flexion motion, and both of them were in increment at over and obese person weight. Moreover, it also appeared that the influence of the magnitude of normal body weight loads on the facet force was less important than that due to overweight and obese weight. This model also can serve to simulate the implants performance including the total disc replacement and fusion techniques.

ABSTRAK

Banyak persatuan perubatan mendefinasikan obesiti sebagai satu penyakit. Berat badan yang berlebihan adalah gangguan serius yang boleh menjejaskan tulang belakang manusia. Obesiti adalah satu faktor yang menyumbang kepada sakit belakang kerana perubahan bagi sifat-sifat mekanikal akibat pembebanan berlebihan. Oleh itu, berat badan berlebihan atau obes boleh menyumbang kepada penyakit yang dikaitkan dengan osteoartritis (OA), facet arthritis sendi, penyakit cakera degeneratif (DDD), stenosis tulang belakang, dan spondylolisthesis. Walau bagaimanapun, kesan berat badan terhadap sambungan facet di bawah beban yang berasingan atau beban mampatan dalam cakera perlu dikenal pasti. Selain itu, dengan menggunakan spesimen dalam ujian biomekanik tulang belakang lumbar terhad dengan kesukaran dalam memperolehi tekanan cakera, ketegangan tulang dan aspek tekanan. Penggunaan kaedah model simulasi dapat menyelesaikan semua kelemahan ini. Oleh itu, matlamat kajian ini adalah untuk membangunkan satu kaedah untuk mensimulasikan biomekanik tulang belakang lumbar, dan untuk menyelidik kesan obesiti pada cakera intervertebral dan aspek bersama di samping menyediakan analisis sistem tulang belakang di antara pelbagai badan berat. Keputusan analisis unsur terhingga akan memberi keputusan yang signifikan jika model yang menggunakan sifat bahan, geometri, mod pemuatan atau syarat-syarat lain yang berbeza. Ini termasuk proses yang digunakan untuk mengubah imbasan CT daripada tulang belakang lumbar ke dalam model simulasi. Proses ini menukar imbasan CT ke dalam fail geometri dan mewujudkan jaringan tulang dan tisu lembut, dan memberikan sifat bahan untuk setiap elemen tulang berdasarkan kepadatan tulang. Model tulang belakang lumbar yang telah dibangunkan dan disahkan dengan kajian sebelumnya. Model unsur terhingga adalah tertakluk kepada beban mampatan 500 N, 800 N dan 1200 N untuk mewakili kes beban normal, berat badan berlebihan dan obes dengan gabungan momen tulen 7.5 Nm dalam keadaan membengkok ke hadapan dan belakang. Keputusan menunjukkan bahawa, terdapat pengagihan tinggi tekanan dan ketegangan di kedua-dua L4 dan L5 dan pada cakera intervertebral dalam ketiga-tiga beban sebelumnya (normal, berat badan berlebihan dan obes). Meningkatkan berat badan akan meningkatkan tekanan nukleus pulposus dan tekanan anulus fibrosus. Tekanan Intradiscal dalam pulposus nukleus meningkat lebih di dalam keadaan membengkok ke hadapan berbanding dengan membengkok ke belakang. Berhubung dengan daya pada facet, bengkokan ke hadapan menyebabkan daya yang lebih besar pada sendi facet sebanyak 21% berbanding bengkokan belakang di dalam keadaan obes. Model ini juga boleh berfungsi untuk mensimulasikan prestasi implan termasuk jumlah teknik penggantian cakera dan fusion.

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LIST OF ABBREVIATIONS

3D	three-dimensional
ALL	Anterior longitudinal ligament
AOA	American Obesity Association
APTA	American Physical Therapy Association's
BMD	Bone mineral density
CL	Capsular ligament
CLa	Conventional laminectomy
CT	Computed tomography
DDD	Degenerative disc disease
De	Dorsal external
Di	Dorsal internal
DICOM	Digital Imaging and Communications in Medicine
FE	Finite element
FEA	Finite element analysis
FEM	Finite element method
FLD	Freedom Lumbar Disc
FSU	Functional spinal unit
ICR	Instantaneous center rotation
IDP	Intradiscal pressure
IGES	The Initial Graphics Exchange Specification
ISL	Interspinous ligament
ITL	Intertransverse ligament
IVD	Intervertebral disc
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
LBP	Low back pain
LF	Ligamentum flavum
MRI	Magnetic resonance imaging
NMR	Nuclear magnetic resonance
PLL	Posterior longitudinal ligament
ROM	Range of motion
S1	First sacral vertebrae
SPiO	Spinous process osteotomy
SSL	Supraspinous ligament
STL	Stereolithography (Standard Tessellation Language)
TDR	Total disc replacement
VLe	Ventral-lateral external
VLi	Ventral-lateral internal
VMS	Von Mises stress

LIST OF SYMBOLS

F	-	Force
N	-	Poisson's ratio
E	-	Young's modulus
ε	-	Strain
C1, C2	-	Material constant characterising the deviataric deformation of material
R	-	Radius
L	-	Length
θ	-	Theta
®	-	Copyright

CHAPTER 1

INTRODUCTION

1.1 Research background

Lower back pain stands out to be one of the most important socioeconomic diseases and one of the most striking health care issues today. The prediction of the spine system's mechanical behavior is one leading issue in biomechanics (Grillo et al., 2005). A better understanding of moving mechanisms of lumbar spine under different loads and stress distribution in this system is highly significant in the advancement of technologies in terms of the spinal restorations intervertebral prostheses, and osteopathic medicine bone (Brunski 1997). The degeneration of the lumbar discs is very much related to Body Mass Index (BMI) where the overweight and obesity person are linked with a higher risk of back pain problems.

Finite element (FE) numerical simulation is a very practical tool for studying the phenomena that cannot be clarified by experimental methods. Moreover, numerical simulation techniques have the potential to lower the costs and to make it less time-consuming during the development of new effective spinal treatment methods or implants executed. Therefore, it is required to find more accurate and correct numerical techniques for the intricate structure of the human spine.

1.2 Problem statement

Obesity has been associated with chronic low back pain (LBP) and this problem is expected to worsen in the near future following the increasing number of overweight and obese people (Zahaf et al., 2015). The abnormal body weight increases the joint stresses in human body (Rohlmann et al., 2007; Leyland, 2007) and this has been addressed as a probable aspect which causes joint degeneration (Vismara et al., 2010; Kurutz and Oroszváry, 2010). Start in previous *in vitro* study, it was shown that immoderate loading on the facet joint is the probable cause for vertebrae failure and, more significantly, vertebrae facet joint failure (Rodacki et al., 2005). Disc height decrease as a result of the compressive load caused by the reduction in the size of gelatinous mass in nucleus pulposus and the fluid being squeezed out of the disc (Bao et al., 1996; Jenkins, 2009). Thus, this intensifies the hydrostatic pressure, further leading to a convexity of outer annulus. Although this mechanism has been explained in various clinical studies, the detailed understanding that backs the biomechanics leading to facet joint damage has yet to be defined clearly. Its long-term clinical outcomes have become an issue raised as the results are not as reliable as it was anticipated (Alekseev, 2002; Belov, 2005; Nikiforov, 2011). Some uncontrolled long-term studies verified that they elevate the pressure and stress occurring on the facet joint, further increasing the possibility of facet joint degeneration.

Therefore, it is important is to understand the consequences of excess compressive load on the lumbar spine and facet joint. The effects of human weight on facet joint in the lumbar spine, however, are still ambiguous since most studies were carried out using certain compressive load of human weight at specific lumbar spine levels (Dreischarf et al., 2010; Moumene and Geisler 2007; Kurutz and Oroszváry, 2010). Additionally, the relationship between the increases in body weight to that of the stresses that occur as the body moves from one place to another needs to be explained. Therefore, it is important to investigate the biomechanical effects of various groups of the human weight in flexion and extension motions on the kinematics of the facet joint in lumbar spine.

1.3 Objectives

The objectives of this work are:

1) To develop and verify a complete three-dimensional FE model of the lumbar spine from L1 to L5 with the corresponding intervertebral discs and facet joints.

2) To investigate the biomechanical effects of obesity on the facet joint of the lumbar spine.

1.4 Scope

The L1-L5 lumbar spine model was developed using Mimics 14.0 software (Materialise, Leuven, Belgium) and 3-Matic 7.01 software (Materialise, Leuven, Belgium) based on CT scan images. The model comprises of soft tissues including intervertebral disc and facet cartilage. Enabling the reconstitution of the vertebra facet joint, and bone using ABAQUS CAE 6.9 finite element software. The parameters examined in this study were the intersegmental rotations of the lumbar spine, pressure within the nucleus, Von Mises stress (VMS) on the annulus fibrosus and the forces of facet joint. Furthermore, human weight were at three types of BMI, normal weight, over weight and obese.

1.5 Significance of study

It has been mentioned in past literature that to delve into and assess the potential risks of other various degenerative facet joint spondylolisthesis, facet joint degeneration could have significant geometrical changes, where the body responds to this additional pressure by developing bone spurs. The facet joints have a strong interaction with the intervertebral discs and significant contribution to control the functional biomechanics of the spine. Furthermore, the understanding of loading acting on the lumbar spine is crucial towards the development of clinical treatments for facet joint troubles. However, the effects of human weight on the facet joint were not really emphasised since the majority of the previous clinical and FE studies were done using certain compressive load of human weight at specific lumbar spine levels (Dreischarf et al., 2010; Zahaf et al., 2015; Moumene and Geisler, 2007). This can be done in the finite element analysis (FEA) as the computational method allows for the modification of forces and moments acting on the FE model of the lumbar spine.

The accuracy of simulation for the anatomy of human lumbar spine and reflection to the biomechanical features is the first step to comprehensively understand biomechanic changes of the spine in case of weight increase, especially that related with obese weight person. Enhanced model will provide a reliable method for further research and contribute to the related biomechanic research of the lumbar spine and facet joint.

The results presented here proves to be valuable not only for future research, but they also highlight the capability in handling a higher compressive load applied to the lumbar spine, although it may be necessary for further studies to be done to offer support to the solution made.