THE STUDY OF HUMAN WEIGHT ON THE BIOMECHANICAL BEHAVIOUR OF INTERVERTEBRAL DISC USING FINITE ELEMENT ANALYSIS

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This report is submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled “The study of human weight on the biomechanical behaviour of intervertebral disc using finite element analysis” is the result of my own work except as cited in the references.

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :. .....

Name of Supervisor : .....

Date : .....

DEDICATION

This thesis is wholeheartedly dedicated to my beloved parents and family, who have been my source of inspiration and constantly provided me with moral, spiritual, emotional and financial support. This is also dedicated to my respectful supervisor for his mentorship throughout this study. Lastly, to my friends who shared their words of advice and encouragement to finish this study.

ABSTRACT

Obesity is a growing healthcare issue, which always associated with different kind of diseases, such as hypertension, osteoarthritis (OA), intervertebral disc degeneration, body pain and difficulty in physical functioning. Excessive load on the spine could change the mechanical behaviour of the lumbar spine and affect 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 are yet to be fully understood. Thus, the purpose of this study was to investigate the biomechanical effects of body weight on the lumbar spine. Finite element analysis (FEA) is a suitable method in the study of intervertebral disc since it can provide a FE model for repeated simulation, which can greatly save the time consuming and more cost-efficient. The finite element model was subjected to follower compression load of 700 N, 900 N and 1300 N to represent the load case of normal, overweight and obese with a combination of pure moments of 7.5 Nm in flexion. 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 contribute to the earliest stages of disc degeneration, which occurs in the nucleus pulposus. In conclusion, flexion increases the nucleus pressure and appears to have differing affects to disc structure. 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.

ABSTRAK

Obesiti adalah satu isu kesihatan yang semakin meningkat dan ia selalu dikaitkan dengan pelbagai jenis penyakit seperti tekanan darah tinggi, osteoartritis (OA), penyakit cakera degenatif, sakit badan dan kesukaran dalam fungsi fizikal. 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 secara biomekanik masih belum difahami sepenuhnya. Oleh itu, tujuan kajian ini dibuat adalah untuk mengkaji kesan biomekanik berat badan pada tulang belakang lumbar. Analisis unsur terhingga (FEA) adalah satu kaedah yang sesuai dalam kajian cekera intervertebral kerana FEA boleh menyediakan model FE yang boleh digunakan dalam simulasi berulang dan membantu dalam menjimatkan masa dan kos. Beban mampatan secara ikutan iaitu 700 N, 900 N dan 1300 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. 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. Kesimpulannya, pergerakan lanjutan meningkatkan tekanan pada annulus dan kesan struktur cakera yang berbeza yang ditunjukkan pada pergerakan akhiran. 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.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBEREVATIONS

AF	Annulus fibrosus
ALL	Anterior longitudinal ligament
CL	Facet joint capsule
DDD	Degenerative disc disease
FE	Finite element
FEA	Finite element analysis
FEM	Finite element method
FSU	Functional spinal unit
IDP	Intradiscal pressure
ISL	Interspinous ligament
IVD	Intervertebral disc
LBP	Low back pain
LF	Flaval ligament
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
NP	Nucleus pulposus
PLL	Posterior longitudinal ligament
ROM	Range of motion
SSL	Supraspinous ligament

TDR	Total disc replacement
TL	Intertransverse ligament
VMS	Von Mises stress

CHAPTER 1

INTRODUCTION

1.1 Background

Low back pain (LBP) is a common symptom, occuring in all age groups, from children to the elderly. LBP brings difficulties to human and affects their quality of life and work, which indirectly caused a great socioeconomic burden to the patients and also society (Manchikanti et al., 2014). It is an ordinary condition that drives individuals to search for remedial treatments (Karppinen et al., 2011).

The main cause of LBP is the natural deterioration of an intervertebral disc (IVD), called degenerative disc disease (DDD) (Abi-Hanna et al., 2018). There are many factors that increased the risk of having LBP in the aspects of psychological, social, biophysical, comorbidities and pain-processing mechanisms such as sitting position, prolonged sitting, obesity, aging and smoking. Prolonged activation of the muscle while sitting may also result in muscle fatigue, in which the mechanical stress on ligaments and intervertebral discs is also increased (Granata et al., 2004).

There were around 34% to 51% of the office workers suffering from LBP within 1 year (Waongenngarm et al., 2018). However, women were the major group to experience LBP among those occupational groups that have been studied, especially nurses where the risk estimated to be in the range of 1.2 to 5.5 (Yassi & Lockhart, 2013). Occupation where men were the majority with a worsen condition of LBP was reported to be construction workers, within the range of 2.3 to 3.0 (Bongert et al., 2004).

Obesity has been recognized as the key factor in radiating LBP regardless in young or adults (Manchikanti et al., 2014). Besides, a study had proved that weight gain led to the increase in the mechanical loading on the lumbar spine, which directly caused a reduction in disc hydration, changed biomechanical and eventually result in disc degeneration and low back pain (Peng et al., 2018). The term ‘disc degeneration’ is a spinal condition involving the natural deterioration of an intervertebral disc such as disc herniation as shown in Figure 1.1 (Abi-Hanna et al., 2018). Disc herniation which also known as disc protrusion or extrusion, led to a focal bulging with 3mm or greater beyond the vertebral margin (Clarencon et al., 2016).

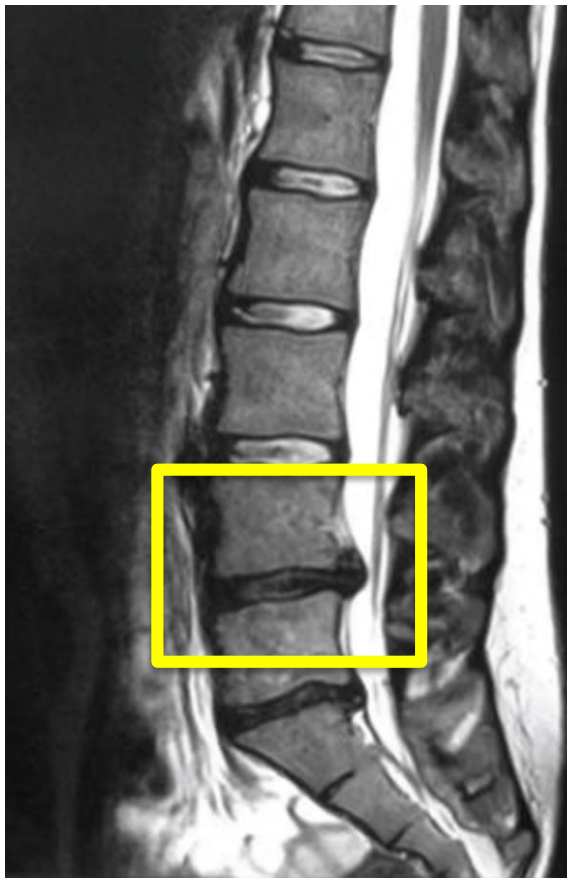

Figure 1.1: Disc herniation in lumbar spine between L4-L5 and L5-S1 (Abi-Hanna et al., 2018).

1.2 Problem statement

Obesity is related to a high prevalence of LBP (Manchikanti et al., 2014). It played a casual role in increasing the mechanical load on the spine, and therefore causing the risk of low back pain (Lake et al., 2000). Extensive studies of the effect of human weight on the biomechanical behavior of IVD have been examined using finite element analysis (FEA). However, some of the researchers used only one component of the IVD in their studies such as only annulus fibrosus was taken into investigation of the degeneration of IVD (Stokes et al., 1987; Iatridis et al., 2005; Karppinen et al., 2011). By using only one component than two components of the IVD will result in different structures and properties.

Besides that, the complete lumbar spine was not considered in some of the studies where only finite element model of a human L4-L5 motion was considered in finite element study (Clarencon et al., 2016; Lee et al., 2016; Bashkuev et al., 2018). It was observed that the whole ligaments were not considered in the study (Hortin et al., 2015). Therefore, this study aims to model the complete lumbar spine including ligaments and nucleus pulposus and annulus fibrosus of IVD.

1.3 Objectives

The objectives of this project are as follows:

1. To improve and verify the finite element model of lumbar spine.
2. To investigate the effects of obesity on the biomechanical behaviour of intervertebral disc.

1.4 Scope of project

The scopes of this project are:

1. To model the ligaments and two parts of IVD, which are the nucleus pulposus and annulus fibrosus, of the current finite element model of lumbar spine using ABAQUS software.
2. To verify the finite element model of the lumbar spine.
3. To examine the stresses of the annulus fibrosus and nucleus pulposus of intervertebral disc at L1-L5 human lumbar spine of different human weight and spine motion.

1.5 General methodology

There are a few methods to be performed in order to achieve this project's objectives. First of all, literature review is important in order to complete this project. Journals, articles and any materials related to the project are gathered from libraries and internet to help readers to understand the information in complete picture.

After collecting information from journals, improvement of finite element model of lumbar spine is performed. The finite element model of the lumbar spine is studied and the model of ligaments is examined to know how it works by using ABAQUS software. The next method used is verification of finite element model to check whether it conforms to its specification. The next step is simulation where the finite element model for normal, overweight and obese weights are made to examine the pressure and stress occurs in the adjacent intervertebral disc.

When simulation is done, analysis and proposed solution is followed. Analysis of the model is interpreted to see the effect of human weight on the biomechanical behaviour of intervertebral disc. Solutions are then proposed according to the analysis. Report writing is the final stage in this methodology where all the information collected is written into a complete report in the final analysis of the project. The methodology used in this study is summed up as shown in the flow chart of Figure 1.2.

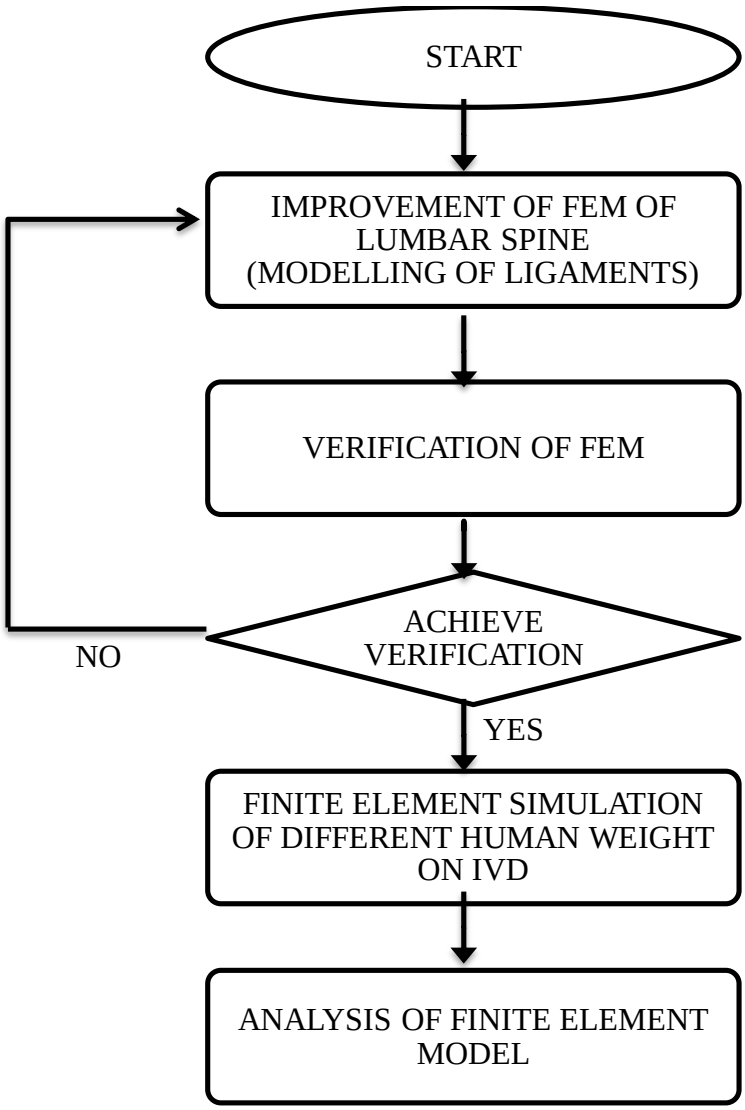

Figure 1.2: Flow chart of the methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter studies the background of LBP and human lumbar spine. The finite element (FE) models of the lumbar spine and intervertebral disc are verified and examined for further research. The directions of human body by referring to the anatomic terms are as shown in Figure 2.1.

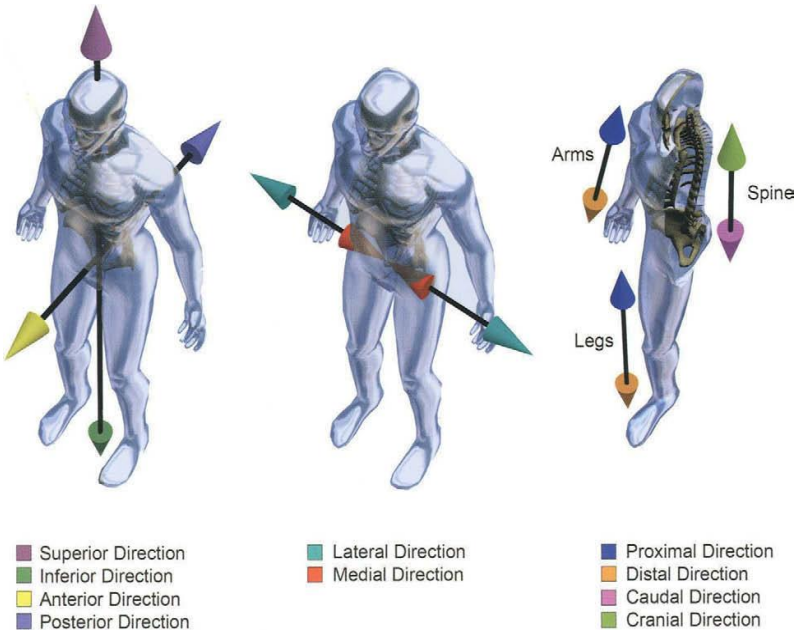

Figure 2.1: Anatomic reference directions (Kurtz and Edidin, 2006).