# INVESTIGATION ON THE EFFECTS OF HUMAN WEIGHT ON SPINAL FACET JOINTS USING FINITE ELEMENT ANALYSIS

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**A report submitted**
**in fulfillment of the requirement for the degree of**
**Bachelor of Mechanical Engineering (Structure & Materials)**

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**DECLARATION**

I declare that this project report entitled “Investigation On The Effects of Human Weight On The Spinal Facet Joints Using Finite Element Analyis” is the result of my own work except as cited in the references.

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|---|---|---|
| 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 (Structure & Materials).

Signature :. ..................................

Name of Supervisor : ...................................

Date : ...................................

**DEDICATION**

This project work is dedicated to my beloved mother and father for always been there to support and inspire me throughout my life.

# 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. Since the obesity has a close relationship with the spinal disorders, it increase the risk and possibility in develop back pain at the lower lumbar spine, which bear the largest mechanical compressive load. Spinal facet joints which are one of the critical components in lumbar spine are thus subjected to high mechanical compressive load and highly exposed to the risk of joint damage and degeneration. Since the concern of facet joints studies with respect to mechanical compressive load is only being given attention recently in this few year due to the difficulty in the modelling of facet surfaces and lack of experimental references related to facet joints, hence, there is a need in the study and analysis of facet joints especially for the effects of human weight on the spinal facet joint. Finite element analysis (FEA) is a suitable method in the study of facet joint since FEA can provide a FE model for repeated simulation which can greatly save the time consuming and more cost-efficient. The main objectives of this study was to develop a verified FE lumbar spine model and investigate the effects of human weight on the spinal facet joint using finite element analysis. The FE lumbar spine was first developed and verified by comparing the intersegmental rotation of the FE model under pure moment of 7.5 Nm in extension and flexion motions with previous in vitro studies. The verified FE model was then subjected to compressive load of 700 N, 900 N and 1100 N, which represented the normal weight, overweight and obese weight to investigate the effect of human weight on the kinematics of lumbar spine and contact pressure on the facet surfaces. The results shown that as the compressive load increased, the intersegmental rotation of lumbar spine and contact pressure on the facet surfaces also increased. Besides, it appeared that L3-L4 region of lumbar spine experienced largest contact pressure compared to other region of lumbar spine in all three loading cases and the contact pressure on facet surfaces during extension motion was much higher than the contact pressure during flexion motion. Moreover, it also found that there was an effect of asymmetry behavior in the lumbar spine.

# *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. Sejak obesiti mempunyai hubungan yang rapat dengan sakit belakang, ia meningkatkan risiko dan kemungkinan dalam mencetuskan sakit belakang di tulang belakang lumbar yang berada di lokasi paling bawah tulang belakang, lokasi menanggung beban mampatan yang terbesar. Sendi facet tulang belakang merupakan salah satu komponen penting dalam tulang belakang lumbar. Oleh itu, ia tertakluk kepada beban mampatan mekanikal yang tinggi dan terdedah kepada risiko kerosakan dan degenerasi sendi. Sejak kebimbangan kajian sendi facet berkenaan dengan beban mampatan mekanikal hanya diberi perhatian baru-baru ini disebabkan daripada kesukaran untuk pemodelan permukaan sendi facet dan kekurangan rujukan eksperimen yang berkaitan dengan sendi facet. Oleh itu, kajian dan analisis sendi facet terutama bagi kesan berat badan manusia pada aspek sendi tulang belakang amat diperlukan. Analisis unsur terhingga (FEA) adalah satu kaedah yang sesuai dalam kajian sendi facet kerana FEA boleh menyediakan model FE yang boleh digunakan dalam simulasi berulang dan membantu dalam menjimatkan masa dan kos. Objektif utama kajian ini adalah untuk menghasilkan satu FE model tulang belakang lumbar yang sah dan menggunakan model FE tersebut dalam penyiasatan kesan berat badan manusia pada sendi facet dengan cara analisis unsur terhingga. FE lumbar tulang belakang dihasilkan dan disahkan dengan membandingkan putaran intersegmental model FE di bawah momen tulen 7.5 Nm dalam pergerakan bengkok ke depan dan belakang dengan kajian dalam vitro sebelum ini. Model FE yang disahkan kemudiannya dikenakan beban mampatan 700 N, 900 N dan 1100 N, mewakili berat badan biasa, berat badan berlebihan dan berat obesiti untuk mengkaji kesan berat badan manusia pada kinematik tulang belakang lumbar dan tekanan sentuhan pada permukaan sendi facet . Keputusan menunjukkan bahawa peningkatan beban mampatan meningkat putaran intersegmental tulang belakang lumbar dan tekanan sentuhan pada permukaan sendi facet. Selain itu, L3-L4 tulang belakang lumbar mengalami tekanan sentuhan terbesar berbanding dengan lokasi tulang belakang lumbar dan tekanan hubungan pada permukaan aspek semasa gerakan bengkok ke belakang adalah lebih tinggi daripada tekanan sentuhan semasa gerakan bengkok ke depan. lanjutan adalah lebih tinggi daripada tekanan sentuhan semasa gerakan akhiran. Selain itu, ia juga mendapati bahawa terdapat kesan asymmetry di tulang belakang lumbar.*

# ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my supervisor Dr. Mohd Juzaila Bin Abd Latif for his guidance, advices and support throughout this project. Secondly, I am also want to take this opportunity to thank UTeM, especially Faculty of Mechanical Engineering for the support of facilities and utilities. I would like to thank my course mates for giving me their support, patience and encouragement. Finally, I would like to thank my family for their support.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| 3-D | Three-dimensional |
| FE | Finite element |
| FEA | Finite element analysis |
| FEM | Finite element method |
| FSU | Functional spinal unit |
| IVD | Intervertebral disc |
| L1 | The first lumbar vrtebra |
| L2 | The second lumbar vertebra |
| L3 | The third lumbar vertebra |
| L4 | The fourth lumbar vertebra |
| L5 | The fifth lumbar vertebra |
| LBP | Low back pain |
| IDP | Intradiscal pressure |
| MRI | Magnetic resonance imaging |
| OA | Osteoarthritis |
| ROM | Range of motion |

## LIST OF SYMBOL

| | | |
|---|---|---|
| F | - | Force |
| v | - | Poisson's ratio |
| E | - | Yong's modulus |
| $C_1$, $C_2$ | - | Material constant characterising the deviatoric deformation of material |
| M | - | Moment |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Low back pain (LBP) is a health disorder which defined as pain and discomfort at the lumbar region of the spine (Koes et al. 2006). A previous studies in United Kingdom reported that LBP is the most common cause of work absenteeism which accountable for about 12.5% of all the sick days and it was estimated that about 80% of adult population will experience LBP at least once during their lifetime (Baliga et al. 2015).

There are many factors that contribute to the LBP, such as obesity, poor posture, lack of exercise, aging, genetic factors and joint injuries. These factors responsible for the osteoarthritis (OA) at the lumbar facet joint which have been recognized as the potential cause of low back pain (Gellhorn et al. 2013; Manchikanti et al. 2016). OA also known as degenerative joint disease can affect any joint and in case of low back pain, OA affects the lumbar facet joint. Facet joint is a synovial joint which is surrounded by a capsule of connective tissue and the joint surface is coated with a layer of cartilage. Facet joint play an important role in transfers load and restricts motion in spine. OA causes the cartilage in the joint to become stiff and lose its functionality as the shock absorber. This results in the joint pain, joint swelling and reduced mobility.

Finite element method (FEM) is commonly use in the study of biomechanics behaviours since it allows repeatable simulation, comprehensive result, rapid time calculation, cost-saving and ethical concerns. FEM is a computational method that discretizes a structure into several elements and describes the behaviour of each element based on the input loading and boundary condition.

## 1.2 Problem statement

Previous studies demonstrated that obesity is strongly associated with low back pain and the cases of obesity is expected to increase further in the future (Shiri et al. 2009). From the previous study, it was found that the body weight is related to the facet joint stress which is always a potential cause of facet joint degeneration (Vincent et al. 2012). Therefore, it is essential to understand the relationship between human weight and the biomechanical effects of the lumbar facet joint. Thus, the aim of the study is to investigate the effects of human weight on spinal facet joint using finite element analysis (FEA).

## 1.3 Objectives

The objectives of this study are:

1) To develop finite element model of lumbar spine.
2) To investigate the biomechanical effects of human weight on the spinal facet joint using finite element analysis.

## 1.4 Scopes of project

The original three dimensional (3-D) L1-L5 lumbar spine model was obtained from the Faculty of Biosciences & Medical Engineering University Technology Malaysia. Three compressive loads which represent normal weight, overweight and obese weight were applied to the finite element (FE) model in this study. The results on the intersegmental rotations of the lumbar spine and contact pressure within spinal facet joint were simulated and presented in this study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

This chapter reviews the background of LBP and human lumbar spine. Besides, the FEA is also outlined in this chapter. Throughout this study, the directions of the human body are referred to the anatomic terms shown in Figure 2.1.

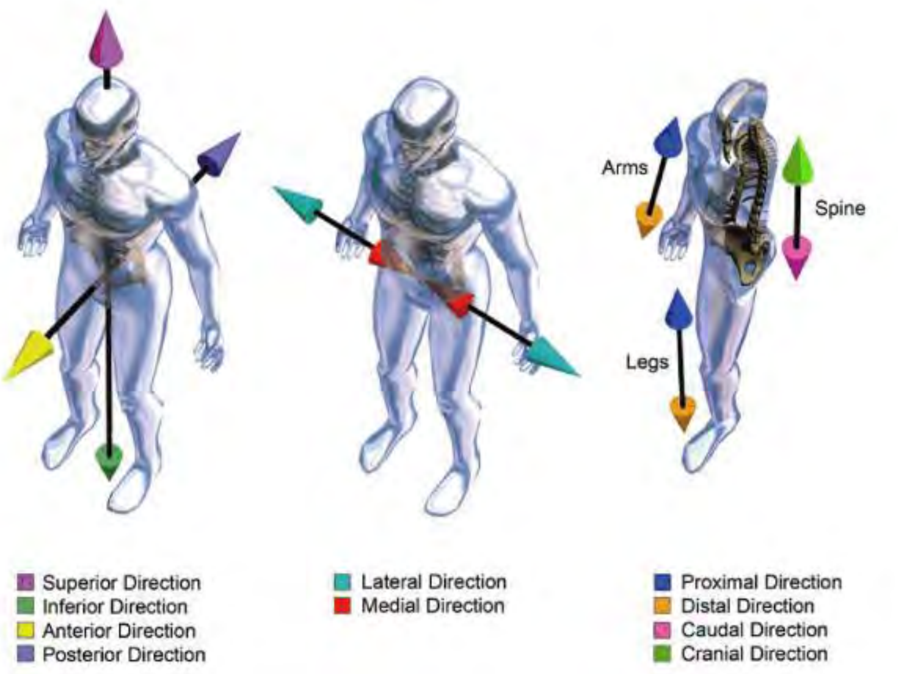


Figure 2.1: Anatomic reference directions. Adapted from Kurtz and Edidin (2006).

## 2.2 Anatomy of the human spine

Human spine is a column of vertebrae which is extended from the neck to the pelvis. The human spine is consisted of 24 individual vertebrae and 9 fused vertebrae (Aleti & Motaleb, 2014). The human spine functions as the support for the body weight, permits limited motion and protects the spinal cord. The human spine has a curvature shape and this curvature is divided into 4 regions, which are cervical, thoracic, lumbar and sacral regions as shown in the Figure 2.2. These curves contribute to the flexibility, stability and shock-absorbing capacity in the spine (Kurtz and Edidin, 2006).

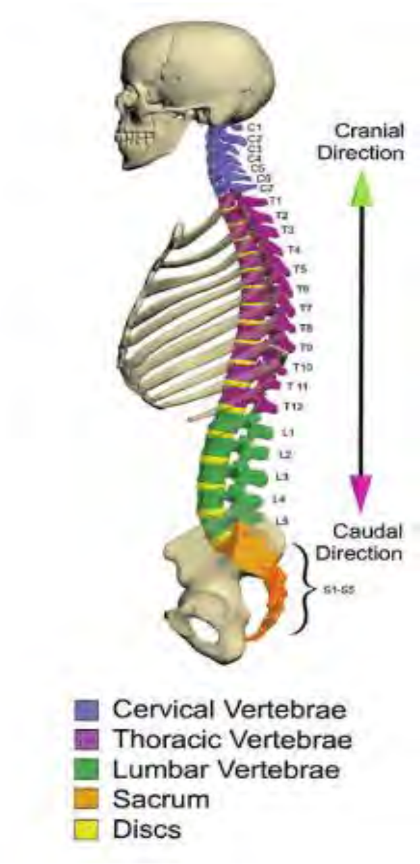


Figure 2.2: Curvature of the spine. Adapted from Kurtz and Edidin (2006).

The cervical spine is located in the neck area and consisted of seven vertebrae which are numbered by C1-C7. These vertebrae supports the weight of the head, allows side to side and nodding motion of the head. The thoracic spine is located in the middle back and consists of twelve vertebrae which are numbered by T1-T12. The thoracic vertebrae is attached to the rib cage and functions as the protection to the heart and lung. The lumbar spine made up of five vertebrae in the lower back, which are numbered by L1-L5. The last region is the sacrum which are located below the lumbar spine. Sacrum is composed of five fused vertebrae which are numbered by S1-S5. The coccyx commonly called as the tail bone and consists of four fused rudimentary vertebrae. Coccyx is located at the terminal portion of the spinal column and it provides attachment for ligaments and muscles of the pelvic floor (Vaccaro, 2005).

## 2.3 Biomechanics of the spine

Biomechanics is the study of biological system using engineering science. It includes the study of mechanical principles, movement and structure of living organism. The biomechanics study of human spine is essential in order to provide more understanding about the spinal stability which played an important role in the support of body weight, allows upright posture and protects nervous structure in the body. These roles place a great strain on the spine and may cause the accelerated aging and symptomatic degeneration (Vaccaro, 2005). The kinematic motion of human spine can be simplified into extension, flexion, lateral bending, axial torsion, traction and compression as shown in the Figure 2.3.

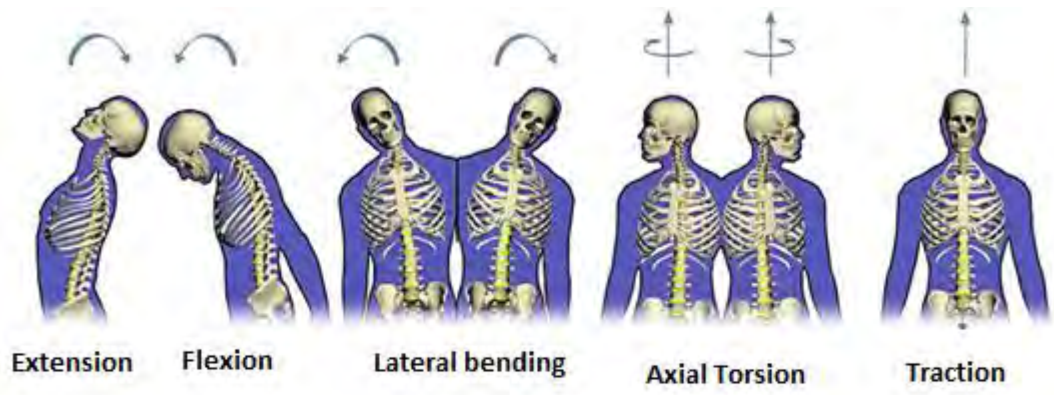


Figure 2.3: The kinematic motions of the spine. Adapted from Kurtz and Eidin (2006).