INVESTIGATION ON THE EFFECT OF HUMAN BODY WEIGHT ON BIOMECHANICAL BEHAVIOUR OF FACET JOINTS USING FINITE ELEMENT ANALYSIS

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DECLARATION

I declare that this project entitled "Investigation on The Effect of Human Body Weight on Biomechanical Behavior of Facet Joints 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 (Structure & Materials).

Signature	:	…………………………
Supervisor's Name	:	…………………………
Date	:	…………………………

DEDICATION

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

ABSTRACT

Obesity is a globally increasing health problem which normally would associate with various kind of diseases such as hypertension, osteoarthritis (OA) and degeneration of soft tissues especially facet joints and intervertebral disc. It is proven that obesity is one of the key contributions that cause low back pain where excessive loading due to obese would change the mechanical behaviour of lumbar spine. The spinal facet joints which serve as one of the load bearers are highly exposed to the risk of joint damage and degeneration when subjected to high mechanical compressive load. Since the concern in studies of facet joints under mechanical compressive load is only given attention in recent years due to difficulties in retrieving its geometrical data and contact pressure. Hence, there is a need to carry out analysis on facet joints especially the effects of human weight on the spinal facet joint. Finite element analysis (FEA) is one of the most suitable method in the study of facet joint since FEA allows repeated simulation which greatly reduce the time consumed and expenditures without compromising the reliability of the results. The main objectives of this study were to improve and verify the FE lumbar spine model and investigate the effects of human weight on the biomechanical behaviour of facet joints through finite element analysis. The ligaments were modelled into the FE lumbar spine model and verified by comparing the intersegmental rotation of the FE lumbar spine model under pure moment of 7.5 Nm in flexion and extension with previous *in vitro* study. The verified FE model was then subjected to compressive follower load of 700 N, 900 N and 1300, which represented the normal weight, overweight and obese weight to investigate the effect of human weight on the kinematics of lumbar spine, stress at capsular ligament and facet contact pressure. The results shown that as compressive load increased, the range of motion for lumbar spine under flexion-extension motion will decrease up to 12%. Besides, it was shown that the stress at capsular ligament and facet contact pressure would increase with increasing compressive load. Under obese weight, the stress at capsular ligament has increased up to 66.75% while facet contact pressure has maximum increment of 19.24% at left superior facets of L3-L4 vertebrae. Therefore, an increase in body weight can change the kinematics lumbar spine and causes an increase in stress at capsular ligament and facet contact pressure. This could be a factor that lead to muscular dystrophy, degeneration of facet joints and osteoarthritis, which are the potential risks for low back pain and chronic low back pain.

ABSTRAK

Obesiti adalah masalah kesihatan yang semakin meningkat secara global dan selalu dikaitkan dengan pelbagai jenis penyakit seperti hipertensi, osteoartritis (OA) dan penyakit cakera degeneratif terutama sendi dan cakera intervertebral. Adalah terbukti bahawa obesiti merupakan salah satu sumbangan utama yang menyebabkan sakit belakang di tulang belakang kerana beban berlebihan akibat obesiti akan mengubah kelakuan mekanikal tulang belakang lumbar. Joint facet spinal yang berfungsi sebagai salah satu penanggung beban sangat terdedah kepada risiko kerusakan sendi dan degenerasi apabila dikenakan beban mampatan mekanikal yang tinggi. Memandangkan keprihatinan dalam kajian mengenai sendi facet di bawah beban mampatan mekanikal hanya diberi perhatian pada tahun-tahun kebelakangan ini disebabkan oleh kesukaran untuk mendapatkan data geometri dan tekanan kontak. Oleh itu, projek ini mengambil kesempatan untuk menjalankan analisis terhadap sendi-sendi facet terutamanya kesan berat badan pada sendi spinal tulang belakang. Analisis unsur terhingga (FEA) adalah salah satu kaedah yang paling sesuai dalam kajian gabungan faset kerana FEA membenarkan simulasi berulang yang dapat mengurangkan masa yang digunakan dan hasil analisis yang tidak menjejaskan kebolehpercayaan keputusan. Objektif utama kajian ini adalah untuk memperbaiki dan mengesahkan model tulang belakang dan mengkaji kesan berat manusia terhadap tingkah laku biomekanik sendi fasa melalui analisis elemen terhingga. Ligamen telah dimodelkan dalam model tulang belakang FE dan disahkan dengan membandingkan putaran intersegmental model tulang belakang FE di bawah momen 7.5 Nm fleksi dan extensi dengan kajian in vitro sebelum ini. Model FE yang telah disahkan kemudiannya dikenakan beban pengikut mampatan 700 N, 900 N dan 1300, yang mewakili berat badan normal, berat badan berlebihan dan obesity untuk menyiasat kesan berat badan manusia pada kinematik tulang belakang lumbar, tekanan pada ligamen kapsul dan aspek tekanan kenalan. Hasilnya menunjukkan bahawa apabila beban mampatan meningkat, pergerakkan tulang belakang lumbar untuk fleksi-extensi akan berkurang sehingga 12%. Selain itu, ia menunjukkan bahawa tekanan pada ligamen kapsul dan tekanan hubungan facet akan meningkat dengan peningkatan beban mampatan. Di bawah berat badan yang obes, tekanan pada ligamen kapsul telah meningkat sehingga 66.75% manakala tekanan hubungan facet mempunyai kenaikan maksimum 19.24% pada bahagian kiri kiri vertebra L3-L4. Oleh itu, peningkatan berat badan dapat mengubah tulang belakang lumbar kinematik dan menyebabkan peningkatan tekanan pada ligamen kapsul dan tekanan hubungan facet. Ini boleh menjadi faktor yang membawa kepada distrofi otot, degenerasi sendi facet dan osteoarthritis, yang merupakan risiko yang berpotensi untuk sakit belakang dan sakit pinggang kronik.

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LIST OF ABBREVIATION

FEM	Finite element method
LBP	Low back pain
DDD	Disc degeneration disease
IVD	Intervertebral disc
AF	Annulus fibrosus
NP	Nucleus pulposus
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
FEA	Finite element analysis
TDR	Total disc displacement
FE	Finite element
ROM	Range of motion
IDP	Intradiscal pressure
PLL	Posterior longitudinal ligament
ALL	Anterior longitudinal ligament
LF	Ligamentum flavum
CL	Capsular ligament

ITL	Intertransverse ligament
ISL	Interspinous ligament
SSL	Supraspinous ligament
OA	Osteoarthritis

LIST OF SYMBOLS

E	-	Young's modulus
v	-	Poisson's ratio
C_1, C_2	-	Material constant characterizing the deviatoric deformation
M	-	Moment
F	-	Force
D	-	Displacement

CHAPTER 1

INTRODUCTION

1.1 Background

Low back pain (LBP) is a health disorder that happens in all especially developed countries and at all age groups. It is reported that about 84% from populations would suffer low back pain in their lifetime (Balagué et al., 2012). LBP is a pain or muscle tension that happens at the lumbar region and could lead to disability and work absenteeism which cause increasing health care cost and socioeconomic burden (Manusov, 2012, Koes et al., 2006).

The causes of LBP include degeneration of intervertebral discs as well as osteoarthritis of facet joints (Schwarzer et al., 1994, Weishaupt et al., 1998). Facet joint is a synovial joint in human spine which locate between the articular processes of two adjacent vertebrae as shown in Figure 1.1. The facet joints play a vital role in transmission of load and stabilise the motion of spine such as flexion and rotation. They also restrict the range of motion for axial rotation. On statistics, study shows that about 15% to 40% of low back pain is due to the facet joint (Dreyer and Dreyfuss, 1996). Osteoarthritis can be defined as degeneration of lumbar facet joints where cartilage cushion deteriorates that lead to formation of osteophyte and subchondral bone sclerosis (Kalichman and Hunter, 2007). This results in the joint pain and reduced flexibility due to rubbing of two adjacent vertebrae.

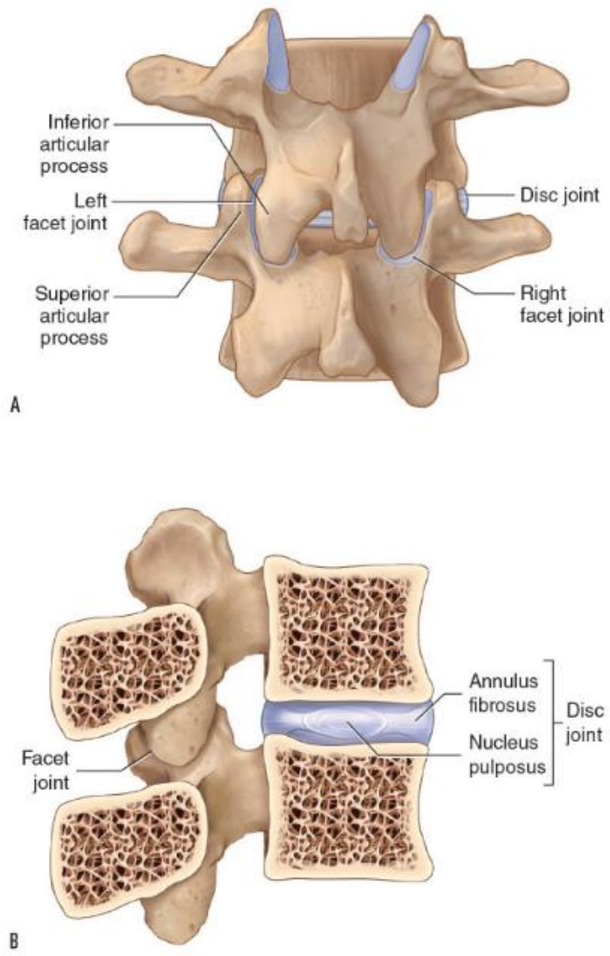

Figure 1.1: The disc and facet joints of the spine. (A) Posterior view. (B) Right lateral view (Muscolino, 2014).

Factors that could lead to LBP include aging, excess weight, smoking habit, poor posture or genetics inherence. All these factors especially obesity could lead to osteoarthritis (OA) at the lumbar facet joint which is reported as possible cause low back pain (Gellhorn et al., 2013, Manchikanti et al., 2016, Walker, 2000). In anatomical perspective, the increased weight will burden the mechanical loading on the lumbar spine, which could cause changes of structure such as osteoarthritis (Peng et al., 2018). Obesity has also been recognised as pandemic. Statistics showed that there has been increased of 28% in adult on prevalence of overweight between 1980 and 2013 (Smith and Smith, 2016).

In order to clearly rectify the relationship between degenerative facet joints from obesity and biomechanical effect of lumbar spine, finite element analysis (FEA) is a good approach to study the relationships. The model of lumbar spine is simulated using FEA which is a computational technique that discretizes the model into finite elements and demonstrates the behaviour of the elements. The FEA is a decent method to be implemented as it provides precise and fast simulation results while allowing repetition of simulation, quick calculation time and cost saving.

1.2 Problem Statement

Previous studies verified that obesity brings significant effect on low back pain (LBP) and with the increasing of prevalence for obesity, this case is predicted to hike in the future (Leboeuf-Yde, 2000, Shiri et al., 2008, Shiri et al., 2010). Obesity also results in increased mechanical stress and would affect the mechanical behaviour at the joint (Leboeuf-Yde, 2000, Vincent et al., 2012).

While FEA studies on biomechanical behaviour of lumbar vertebrae has been widely carry out by previous studies, some of the studies did not implement the whole lumbar vertebrae in the FE models (Schmidt et al., 2008, Goel et al., 1993, Zahari et al., 2017). Besides, modelling of capsules is sometimes given less emphasis and instead contact pair surface method is used to represent capsular ligaments of facet joint (Kuo et al., 2010).

Therefore, this study aimed to examine the effect of human body weight on the facet joint using an improved lumbar spine model.

1.3 Objective

There are two main objectives in this study:

1) To improve and verify the finite element model of the lumbar spine.
2) To investigate the effect of human body weight on the biomechanical behaviour of facet joints.

1.4 Scope

In this study, capsular ligaments in the facet joints of lumbar spine were modelled in existing FE lumbar spine model using ABAQUS software to replicate the actual physiological behaviour of the spine. Then, the lumbar spine model was verified with the previous experiment study to make sure simulation results are valid. The stresses at the facet joints were examined at different human weight and different spine motion such as flexion and extension.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discusses about LBP and human lumbar vertebrae. The FEA of lumbar vertebrae will also be outlined as it brings remarkable results for future research to reduce problems on real human lumbar vertebrae. Throughout this study, the anatomy directions of human body are shown according to the terms in Figure 2.1.

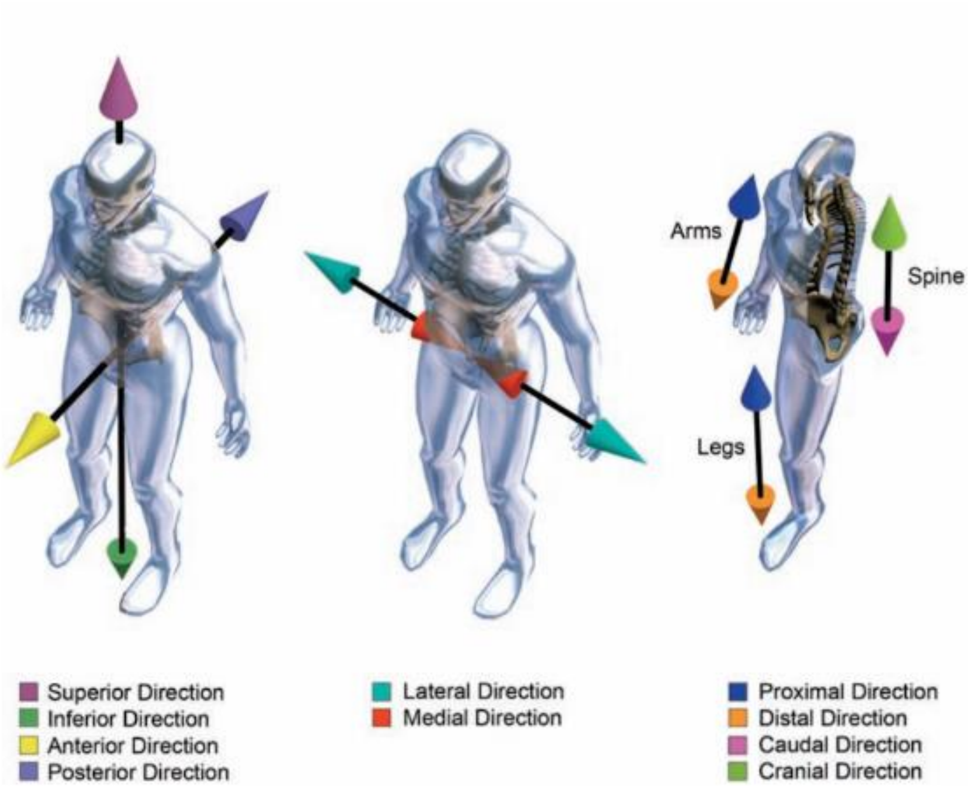

Figure 2.1: Anatomic reference directions (Kurtz and Edidin, 2006).

2.2 Biomechanics of human spine

Biomechanics of spine shows the study of structure and function of spine in mechanical aspects. It is important as it help us to understand how our body structures work and function especially our skeletal system. In order to gain more understanding on human spine which acts as main support for human body and stability, the application of biomechanics study of human spine is important and need to be carried out from time to time.

The biomechanical intents of spine are to serve as structural support for the body while permitting trunk movement as shown in Figure 2.2. It also protects the nerves that connect periphery to brain. The integration of spine stability and mobility is important to achieve these roles concurrently (Bergmark, 2009). The spine also distributes the upper body weight to pelvis with internal forces outnumber the whole-body weight. The kinematics motion patterns of spine are complex due to its flexibility. However, it can be classified into flexion, extension, lateral bending, and axial rotation. (Sarathi Banerjee, 2013)

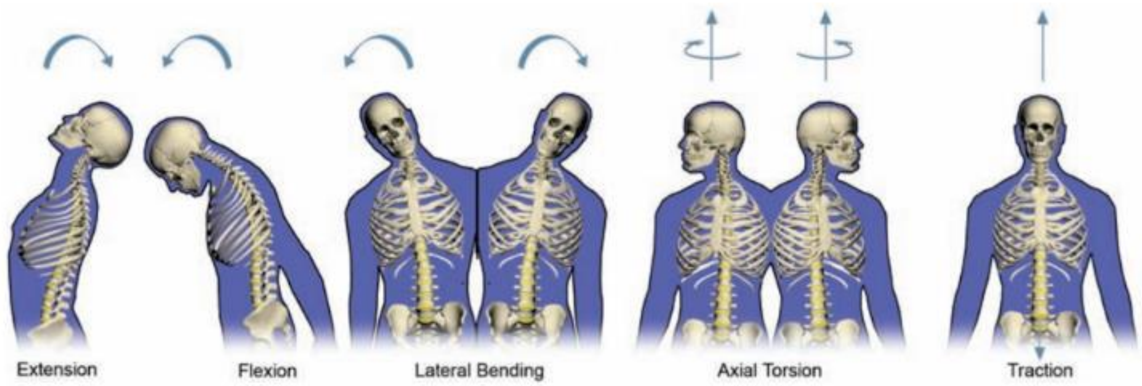

Figure 2.2: Types of motions of the spine. (Kurtz and Edidin, 2006)