MODELING ANALYSIS OF MENISCUS OF KNEE JOINT DURING SOCCER KICKING

MOHD FIRDAUS BIN MOHD JAAFAR

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Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

The meniscus is important in many aspects of knee function. The placement of meniscus where been located between the two bones of femur and tibia gives an advantage towards the knee joint. It is when the load been transmitted across the joint in order to give maximal congruency towards the joint. This study will focuses on two objectives which are to observe the effects towards the knee joint which having various cases of meniscus and also to observe the functionality of the meniscus which is wedges in shape. The method used in this study is a simulation of knee joint which is consisting of three main parts, femur, tibia and meniscus. In order to observe what the effects towards the knee joint, various cases is being simulated which are knee joint with healthy meniscus compared with knee joint with various of torn meniscus and a simulation of full leg with and without knee pad with existence of external impact. The boundary condition of force parameter is calculated from the ball velocity after being kicked where the comparison between the two types of kicking result with instep kicking got high impact force and distributed force than inside kicking. The highest distributed force then is used for the simulation. Simulation result shows that a healthy meniscus transmits load across the joint in a uniform state within the range of 0.3 MPa and 0.4MPa. For torn meniscus, the result shows that it is failed to transmit the load across the joint. Thus an excessive stress is recorded across the surface of the tibia. The highest stress recorded is 0.5 MPa. For second simulation, 1000 N is used as an external force exerted to the leg surface. Result shows that the external force applied on the surface of the leg will give an effect towards the internal part of the knee joint where causing the knee joint to bend and meniscus to be compressed. Comparison between the full leg with and without knee pad shows that full leg without knee pad is having large of knee joint bending and meniscus be compressed more than full leg with knee pad. From these to simulation, an observation can be made where the placement of the meniscus between the femur and tibia is to maintain the congruency between the bones and to prevent an excessive stress happen to the joint.

ABSTRAK

Meniskus merupakan sesuatu yang penting terhadap lutut manusia. Tempat di mana meniscus berada memberi kelebihan kepada lutut manusia Hal ini demikian kerana apabila beban melalui sendi lutut manusia, beban tersebut akan disebarkan terus ke permukaan tulang sendi. Ini membuatkan sendi lutut manusia dalam keadaan yg selesa tanpa tekanan berlebihan. Objektif utama projek ini adalah untuk mengenalpasti kesan yang berlaku tehadap sendi lutut di dalam dua keadaan iaitu sendi lutut yg mempunyai meniskus yang sihat dan juga sendi lutut yang mempunyai meniskus yang koyak. Di samping itu juga, objektif projek ini adalah untuk melihat keberkesanan bentuk meniskus di antara dua tulang penting iaitu tulang peha dan juga tulang kering. Bagi melihat kepentingan meniskus dan apa kesan yang terjadi terhadap meniskus, simulasi dilakukan. Reka bentuk lutut yang dibuat mengandungi 3 komponen iaitu tulang paha, tulang kering dan juga meniskus. Simulasi yang berlainan juga dilakukan di mana kaki lengkap bersama penutup lutut dan juga kaki lengkap tanpa penutup lutut dengan kehadiran beban dari luar. Simulasi pertama dilakukan dengan menggunakan beban yang dikira daripada kelajuan bola selepas disepak di mana perbandingan di antara dua jenis sepakan. Keputusan menunjukkan sepakan jenis ‘instep’ mempunyai beban yang tinggi dan juga sebaran beban yang tinggi. Sebaran beban yang tertinggi akan digunakan untuk melaksanakan simulasi. Keputusan simulasi menunjukkan meniskus yang sihat menghantar beban secara seragam di dalam lingkungan 0.3MPa sehingga 0.4 MPa untuk setiap nodus di atas tulang kering. Bagi simulasi lutut dengan meniskus yang koyak, keputusan simulasi menunjukkan meniskus gagal untuk menghantar beban secara seragam di mana ada tekanan yang tinggi di beberapa nodus. Tekanan tertinggi direkodkan adalah sebanyak 0.5 MPa. Bagi simulasi kedua, 1000 N beban digunakan untuk ditujukan kepada permukaan lutut. Keputusan menunjukkan beban dari luar tetap memberi kesan terhadap bahagian dalam lutut. Kesan yang berlaku menyebabkan lutut bengkok dan meniskus ditekan sehingga berlaku perubahan bentuk meniskus. Perbandingan di antara kaki lengkap bersama penutup lutut dan tanpa penutup lutut menunjukkan penutup lutut berupaya mengelakkan lutut bengkok secara maksimum dan perubahan yang banyak terhadap bentuk meniskus. Bagi kedua-dua simulasi yang dilakukan, satu pemerhatian boleh dilakukan di mana meniskus yang berada di anta dua tulang adalah untuk memastikan kedua-dua tulang tersebut di dalam keadaan yang selesa tanpa kehadiran tekanan yang tinggi berlaku .

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E	Young's modulus elasticity
a	Acceleration
ϵ	Strain
σ	Stress
m	Mass
v	Velocity
t	Time
F	Force
ρ	Density
%	Percentage

LIST OF ABBREVIATIONS

ANSYS	Analysis of System
3D	3 Dimensional
UMP	University Malaysia Pahang
FEA	Finite Element Analysis
MRI	Magnetic Resonance Imaging

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Human knee is one of the largest and complicated joint that placed between the thigh and shank. All movement that related to leg will be restricted if the knee is injured. That shows how important is the knee towards our body in term of motion. The upper leg bone (femur), lower leg bone (tibia), meniscus, cartilages and ligaments are the important parts of knee joint. In this study, ligaments and cartilage will be ignored and stress more on femur, tibia and the meniscus.

Soccer is one of the sport activities that got many impressions throughout the world. The popularity of the sport itself is depends on the player's popularity in term of his skill and ability. On the part of his skills and ability, there is biomechanics that work on his body. This biomechanics can be divided into many parts such as on the foot which is used to kick the ball, on the head which is used to heading the ball and so on. In this study, the focus will be more on the knee joint in order to see the effect of knee meniscus that located between the joint while player kicking the soccer ball.

Meniscus is one of the parts that consist on human knee joint located between the joint of femur and tibia. Meniscus has always been loaded by an axial force either from the upper part of the body or the lower part of the body. It is a fact that, a body that being loaded continuously will get defect. It is same goes to the meniscus. Common meniscus disorders are the meniscal tears. It is the result of stresses that act through the meniscus body. In this study, we will see the effect towards meniscus during soccer kicking in term of its movement and its stress distribution.

1.2 PROBLEM STATEMENT

Knee is a part of the body that located between thigh and shank is one of the most complicated and largest joint in human body. The knee has to support nearly the whole of human's weight, so that it is easy for the knee to get injured. The common injuries that occur are ligaments, meniscus or bone fracture which are internal part of the knee.

"Most injuries that occur in the knee either cause meniscal damage or are the function of previously damaged meniscus, a complex tissue that has been historically underappreciated." (Fening, 2005)

For soccer games, knee is the most critical part that will easily get injured due to the shock from an external impact. Torn meniscus is one of the effects. This study will learn about the effect towards the knee joint having healthy meniscus compared with the different types of torn meniscus within the joint.

"Most of the tears (73%) occurred in athletes who were soccer player, basketball players, or skiers. The medial meniscus was torn more frequently than the lateral which is 70% of the tears in the study was medial" (Knee Injuries, 2012)

From the statistic, it is shows that the meniscal tear is the common disorder that act towards the knee meniscus. The common factors are from the knee twisting and pivoting but it is also may come from the force distributed from the feet towards the knee joint. In this study, we want to see the effects that happen towards the meniscus when someone kicking the ball.

1.3 OBJECTIVE

The objectives of this project are to predict the effect towards the knee joint with the healthy meniscus compared with knee joint with different type of torn meniscus and to observe meniscus properties which are its wedges shape.

1.4 SCOPES

The scopes of this project are as follows:

1. Limited to 3D modeling of knee joint consist of femur, tibia and meniscus.
2. Study on stress reading on the surface of the tibia.
3. Study on two types of kicking which are inside kick and instep kick.
4. Study the effect of meniscus by simulating full leg with and without knee pad.

1.5 ORGANIZATION OF THESIS

In this thesis, it is consisting of five chapters where chapter 1 is focuses on the background of the study, the problem statement, objectives and scopes. Chapter 2 is focuses on the summary of journals where several topics will be discussed regarding the study. Out of 15 journals, 5 topics are listed out. Chapter 3 is discussing on the flow of the project from the beginning till the end. In addition, the method used in this study will also be discussed in this chapter. Chapter 4 is focuses on the result of the study. The result will be discussed on how and why this happen in orders to get the conclusion of the study. Last but not least, Chapter 5 is a part where the conclusion of the study will be discussed and several recommendations for future use.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the basic knowledge which related to the human knee joint will be described in it. A simple explanation and introduction to the femur, tibia and meniscus will be defined. There will be three topics that will be discussed regarding the knee meniscus in this chapter which are meniscal function, meniscal movement, the common meniscus disorder. Last but not least, an explanation that related to the soccer which is instep kicking and inside kicking will be explained. Some journal and article which are highly related to this study will be summarized.

2.2 FEMUR BONE

The femur is the longest and strongest bone in the skeleton is the most closest to the center of the body. Femur is said to be 26% of the person height since it is the longest bone. Two femurs is converge towards the knee and end at the upper surface of the tibia. Femur is the main bone that remote all the movement since it is the connecter between the bottom of the body and the hip. Figure 2.1 shows the knee anatomy consisting of femur. (Knee Anatomy, 2013)

2.3 TIBIA BONE

The tibia or the other name is shin bone o shank bone is the two bones that located below the knee. The upper part of the tibia is consisting of two flat-topped that articulate with upper bone which is femur. Tibia also is the connector between the knee

and the ankle bone. Tibia is recognized as the strongest weight bearing bone of the body. Figure 2.1 shows the knee anatomy consisting of tibia. (Knee Anatomy, 2013)

2.4 KNEE MENISCUS

Meniscus of the knee is a complex structure that can be found within each knee between the upper leg bone, femur and lower leg bone, tibia. The study about the knee meniscus will enhanced the understanding of its function and its roles towards human body. (McDermott *et al.*, 2008)

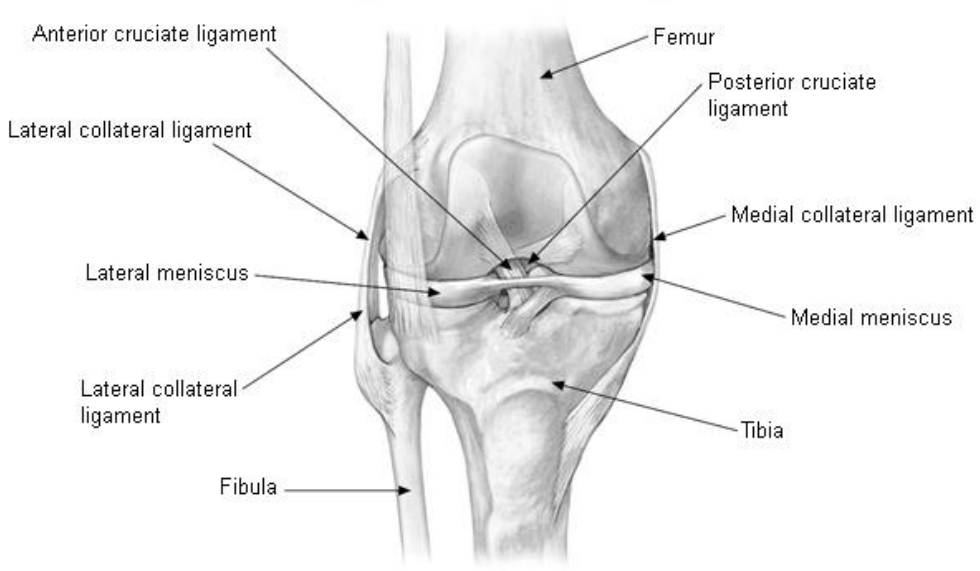


Figure 2.1: Human right knee anatomy
Source: Human Knee Anatomy (2012)

2.4.1 Medial Meniscus

Medial meniscus which is semilunar in shape is larger than the lateral meniscus. The capsular and bony attachments of the medial meniscus constrain its motion, possibly accounting for the higher frequency of injury. (Lee *et al.*, 2000)

2.4.2 Lateral Meniscus

The lateral meniscus is more circular in shape and the dimension of the posterior and anterior is the same. Lateral meniscus is covering more surface area of tibia because of its more circular in shape. (Lee *et al.*, 2000)

2.5 SUMMARY OF JOURNALS

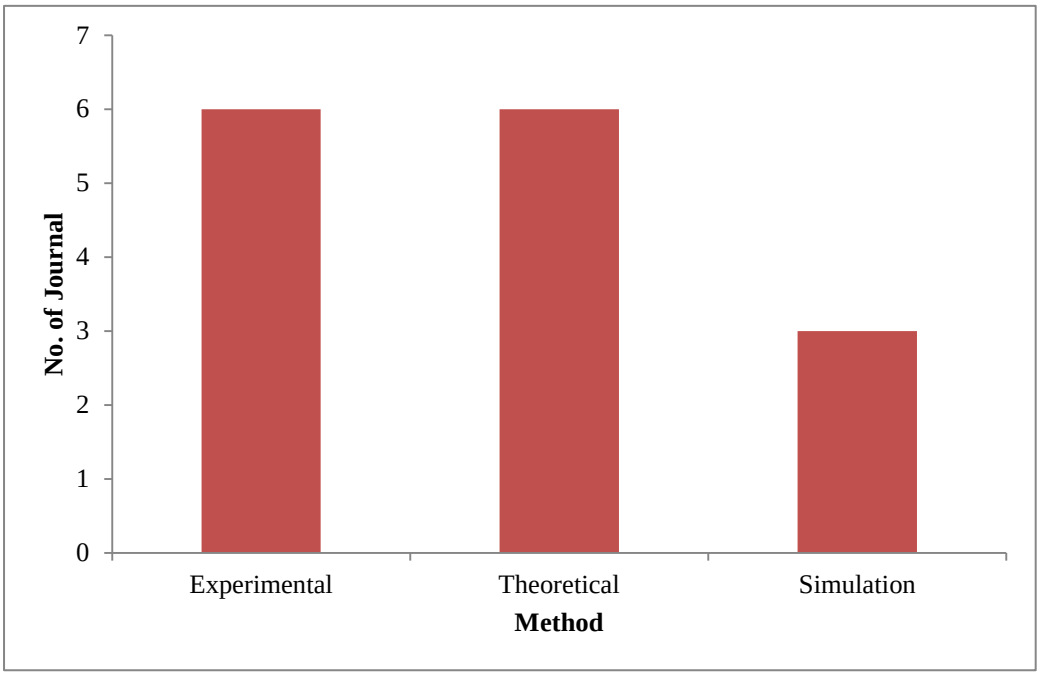


Figure 2.2: Method of journal

Fifteen of journals have been reviewed and each of the journals is using difference kind of method. Three methods is been classified which are experimental, theoretical and simulation. Experimental method is where the author is using an experimental approach to do the project. Theoretical approach is where the author is discussed the topic throughout his project and lastly the simulation method is where the author simulating the design in order to get the result. From the Figure 2.2, it is stated that out of 15 journals, 6 journals is using the experimental and theoretical method and 3 methods is using simulation approach. The list of journals used can be seen in Table B-1 in Appendix B.

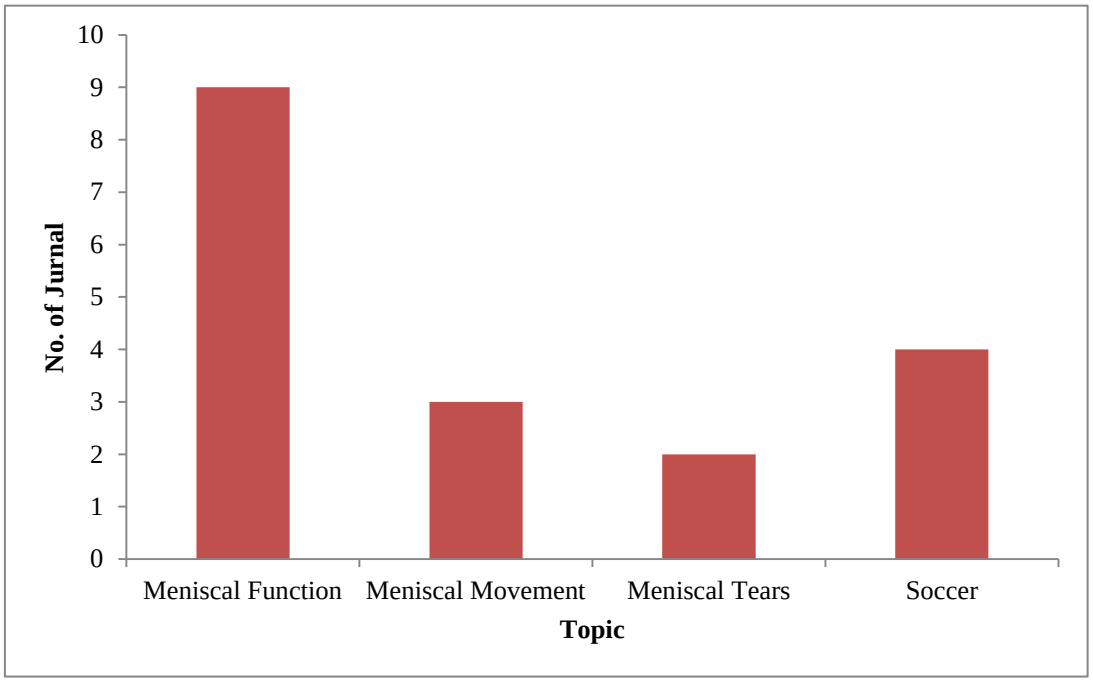


Figure 2.3: Topic of journal

Fifteen of journals have been reviewed that discussed about the general view of meniscus and regarding the soccer. Three topics will be discussed deeply about the meniscus which are meniscal function, meniscal movement, meniscal tears, and other three topics regarding the soccer which are Soccer Disease, Instep Kick and Inside Kick.

2.5.1 Meniscal Function

Meniscus is an internal part of the body that found between the femoral condyles and tibial plateau. There are two types of meniscus within the knee joint, which are medial and lateral. These two crescent shape cartilages is a fibro cartilageous structure, which is made up from a network of collagen fibres. The meniscus is one of the complex structures that having various function towards the human body. The function of the meniscus is been discussed a lot by researchers in their literature. The meniscus acts an important role towards the knee in order to protect the joint between the femur and tibia. The main function of meniscus is to distribute the load across the joint between femur and tibia. Other than that, meniscus is also act as stabilizer between the

joint, joint lubrication and so on. Many literatures discussed about its main function that is load transmission. By distributing the load across the joint, this will ensure the stability of the joint. This will result the stress experienced by the joint been decreased. Figure 2.4 shows the different between the knee with meniscus and without meniscus.

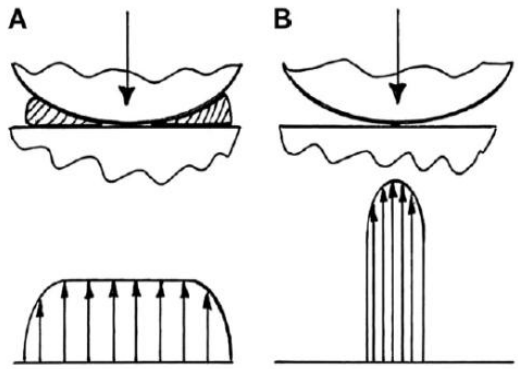


Figure 2.4: Differences between the knee with meniscus and without meniscus
Source: McDermott *et al.* (2008)

The common description of the meniscus is that they are semi-lunar fibrocartilagenous disks, whose main function is to increase the congruency of the tibiofemoral joint, thereby decreasing the stress in the joint through an increase in the contact area. (McDermott *et al.*, 2008). Since the meniscus is a viscoelastic material, it will tend to compress when the load is applied. As the femur and tibia is moving, the meniscus is also will move, so that the congruency of the joint can be maintained. When the meniscus move from its original shape, it shows that force is being transferred across the meniscus body. This is called the hoop stresses that act within the meniscus body. The compression force across the knee, as it is transmitted from the femur through the meniscus to the tibia, causes tension along the circumferential collagen fibres within the meniscal tissues. (McDermott *et al.*, 2008)

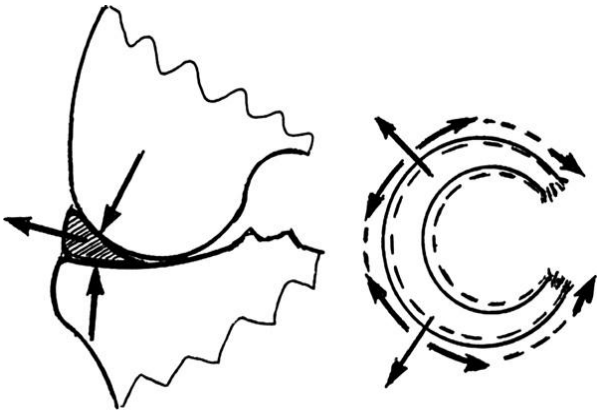


Figure 2.5: Conversion of axial load into meniscal hoop stresses.
Source: McDermott *et al.* (2008)

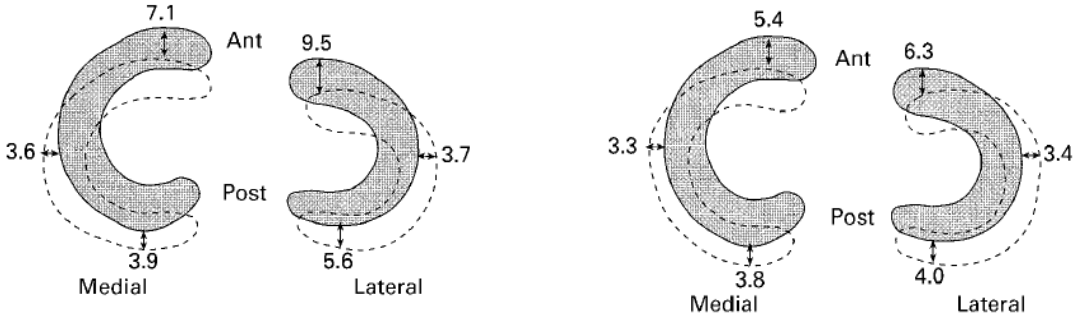
McDermott *et al.* (2008) stated in the literature regarding the development of hoop stress within the meniscus body, it is a result from a net resultant force that generated when load is applied. The wedge shape of meniscus after being loaded will make it to extrude from its original shape and creates a more congruent surfaces between the femur and tibia. Therefore, the transmitted and distributed load that across the upper or lower bone will over the large surface area. In order to prevent the meniscus from extrude more, hoop stresses is developed. Compression force that act towards thee knee joint will cause the meniscus to move and change in shape. Movement of the meniscus during knee flexion ensures maximal congruency with the articulating surfaces while avoiding injury to it. Dynamic congruity facilitates load transmission, stability, and lubrication. (Vedi *et al.*, 1999)

2.5.2 Meniscal Movement

Meniscus of the knee is having viscoelastic properties that are described as a combination or mixture of solid and also fluid components. Viscoelastic and elastic has their own properties. For elastic material, Viscoelastic and elastic material is having a different meaning and properties. In an elastic material, the energy used to deform the material is equal to the integral of the force deformation curve. (Andrews *et al.*, 2011). That is mean, when loading and unloading process; there will be no energy loss or any energy absorption. This is opposite with the viscoelastic condition. When loading and

unloading process, the energy between those two works will not the same. The energy loss phenomenon is due to the movement of fluid and/or the rearranging of molecule structure of the tissue itself. (Andrews *et al.*, 2011)

Since the meniscus is having fluid structure in its cross section, the meniscal water content could be extruded either by compression or by direct application of a pressure differential. (McDermott *et al.*, 2008). This will result with the displacement or deformation of meniscus that is to maintain the congruency of the femur and tibia joint, hence, the meniscus will carry about 40% to 70% of the load across knee. (Vedi *et al.*, 1999). When load is applied, force distribution will go through the femur and the meniscus will experienced the force. The fluid components of meniscus will slowly to extrude depends on its permeability and the viscosity of fluid. Vedi *et al.* have done experimental setup by testing subject's knee joint to determine the meniscal movement through an arc of flexion-extension while weight bearing. The result state that the menisci do move posteriorly as the knee flexes and the lateral meniscus did move more compared to the medial meniscus. (Vedi *et al.*, 1999)



a) b)

Figure 2.6: Mean movement in each meniscus a) weight bearing b) unload knee

Source: Vedi *et al.* (1999)

From the results, it shows that the movement of the meniscus during the knee-flexion is to ensure the maximum congruency of the joint and also the articulating surfaces in order to avoid it from injury when having load. The result also state that the lateral meniscus did move more than medial meniscus. This is because there is no attachment between the lateral meniscus to any ligament compared with medial

meniscus which attached to the medial collateral ligament. That is why the mobility of medial meniscus is restricted compared with the lateral meniscus which moves more when being loaded or flexion-extension happens.

2.5.3 Meniscal Tears

Knee meniscus is a two semicircular pad that can be found between the joint of upper leg bone (femur) and lower leg bone (tibia). It is become the function of meniscus to be an effective load transmission, so that the joint congruency can be enhanced. All material that is continuously loaded will have defect on its body. Same goes with the meniscus. The common defects that always occur are meniscus tear. Meniscal tears can happen to everyone without notice. Whether the age is young or old, everybody have a chance to get it depends on their lifestyle. At the young age, meniscal tears are caused by trauma in which happen while they are doing activity. In case, their knee is pivoted or twisted while they are doing activity, the meniscus can be torn. For old age, meniscus tears are a common thing for them. It is because the fluid structure within the meniscus will degenerate as their age is increased (Meniscus Disorder, 2012)

There are many types of meniscus tears that can be classified. Meniscal tears can be classified according to their location, shape, size, and stability. The classified tears are vertical longitudinal, oblique or called as parrot beaked, displace or called bucket handle, degenerative, transverse, horizontal or complex. Out of those tears, the most common tears that always occur are vertical longitudinal and the oblique tears. About 81% of the meniscus tears are parrot beak or longitudinal tears affecting more often the medial meniscus. (Pena *et al.*, 2005). Figure 2.7 shows a certain pattern of tears that happen at the knee meniscus.

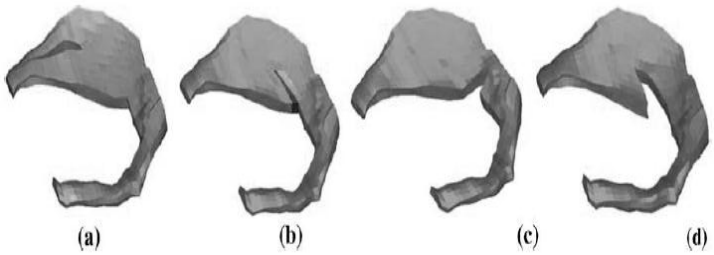


Figure 2.7: Patterns of meniscal tear: a) longitudinal b) oblique c) transverse d) parrot beak.
Source: Pena *et al.* (2005)

Once the meniscus torn, surgical is the best way to prevent any compilation happens towards the knee joint. If not, the continuous knee motion and continuous load applied towards the meniscus can worsen the original tear. The surgical way that is one of the best is meniscectomy. Meniscectomy is a step to alter the shape of meniscus or remove the tear part of the meniscus. There are also different types of meniscectomy which are longitudinal, radial, oblique and total. After meniscectomy is done towards the torn meniscus, it will result with effect towards the joint of femur and tibia. Meniscectomy dramatically alter the pattern of static load transmission of the knee joint. (Pena *et al.*, 2005). This is because the fluid structure within the meniscus is being altered and the way of meniscus distributing the load will be different with the healthy meniscus. Hoop stresses are lost when a radial tear occurs or a segmental meniscectomy is performed; the load bearing condition become similar to that after meniscectomy. (Lee *et al.*, 2000). Figure 2.8 shows a difference of load distributing between a healthy meniscus and also meniscus after meniscectomy.