FINITE ELEMENT ANALYSIS ON HUMAN KNEE

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ABSTRACT

Three dimensional model of human knee were developed to clarify the causes of knee joint injuries such as osteoarthritis, bursitis, and ligament tears. The model developed allowed the simulation by the performance of Finite Element Analysis (FEA) of different angles and different forces. The purpose of this study is to evaluate the result of kneeling 60 degree, kneeling 90 degree, and squatting to the knee joint with and without kneepad. However, this study is focused for construction worker such as mining worker. This study was simulated by using Autodesk Simulation Multiphysics to solve the finite element analysis. There are several crucial points to the proper application of numerical method such as the geometry, material properties, and boundary condition must be created to solve the finite element analysis that must have in finite element method. The force applied is at the area patella with the value of 303N, 603 N, and 903 N. The femur bone, tibia bone, and patella are assumed as rigid body. From the result the effect of kneeling 90 degree, kneeling 120 degree flexion, and squatting to the patella., the maximum stress on patella of 90 degree flexion is higher because have larger contact surface area as the knee was bent than 60 degree flexion and 120 degree flexion. For stress vs. deformation for cartilage, the position of 90 degree flexion give the higher stress and deformation as the stress on patella was high the stress to the cartilage became higher the contact stress of patella occur at the superior half of the patella and an area of the femoral groove just above the notch that means the contact stress of patella to cartilage 90 degree flexion was larger than 60 degree and 120 degree flexion. As for ligaments, at 90 degree flexion, the higher stress occur at ACL for without and with kneepad with the value 0.507 MPa and 0.0667 MPa with the percentage of absorption to the kneepad is 86%, followed by PCL 98.5 %. MCL is 99.4%, and LCL 98.5 %. From the result, it is true that the most common ligament injuries in mining or construction worker is ACL tear as the results shows that ACL gives highest stress that other ligaments. PCL had lower stress than ACL as in medical, PCL gives far less common injury than ACL because of PCL function itself that maintaining joint normal function. From the research, it can be concluded that wearing the kneepad will reduce the stress on knee ligament of construction worker to prevent injury and knee pain.

ABSTRAK

Tiga model dimensi lutut manusia telah dibangunkan untuk menjelaskan sebab-sebab kecederaan sendi lutut seperti osteoartritis, radang kandung lendir, dan koyak ligamen. Model ini dibangunkan dibenarkan simulasi oleh prestasi Analisis Unsur Terhingga (FEA) daripada sudut yang berbeza dan daya yang berbeza. Tujuan kajian ini adalah untuk menilai hasil daripada melutut 60 darjah, melutut 90 darjah, dan setinggan untuk sendi lutut dengan dan tanpa kneepad. Walau bagaimanapun, kajian ini memberi tumpuan kepada pekerja pembinaan seperti pekerja perlombongan. Kajian ini adalah simulasi dengan menggunakan Multiphysics Simulasi Autodesk untuk menyelesaikan analisis unsur terhingga. Ada beberapa perkara penting untuk permohonan yang betul kaedah berangka seperti geometri, sifat bahan, dan keadaan sempadan perlu diwujudkan untuk menyelesaikan analisis unsur terhingga yang mesti mempunyai dalam kaedah unsur terhingga. Daya dikenakan pada kawasan patela dengan nilai 303N, 603 N, dan 903N. Tulang paha, tibia tulang, dan patela dianggap sebagai satu badan tegar. Dari hasil kesan melutut 90 darjah, melutut 120 darjah akhiran, dan setinggan untuk patela. Tekanan maksimum pada patela daripada 90 darjah akhiran adalah lebih tinggi kerana mempunyai hubungan yang lebih besar kawasan permukaan sebagai lutut telah bengkok daripada 60 darjah dan 120 darjah. Untuk tekanan vs ubah untuk cartilage, kedudukan 90 darjah akhiran memberikan tekanan yang lebih tinggi dan perubahan bentuk seperti tekanan pada patela adalah tinggi tekanan kepada cartilage menjadi lebih tinggi tekanan hubungan patela berlaku pada separuh atasan patela dan kawasan alur femoral di atas kedudukan yang bermaksud tekanan hubungan kepada rawan patela 90 darjah akhiran adalah lebih besar daripada 60 darjah dan 120 darjah akhiran. Bagi ligamen, pada 90 darjah akhiran, tekanan yang lebih tinggi berlaku pada ACL kerana tanpa dan dengan kneepad dengan nilai 0,507 MPa dan 0,0667 MPa dengan peratusan penyerapan kepada kneepad adalah 86%, diikuti oleh PCL 98.5%. MCL adalah 99.4%, dan LCL 98.5%. Dari keputusan itu, ia adalah benar bahawa kecederaan ligamen yang paling biasa dalam perlombongan atau pembinaan pekerja adalah ACL pemedih mata kerana keputusan menunjukkan bahawa ACL memberikan tekanan tertinggi yang ligamen lain. PCL mempunyai tekanan yang lebih rendah daripada ACL dalam perubatan, PCL memberikan kecederaan yang jauh lebih rendah daripada biasa ACL kerana fungsi PCL sendiri yang mengekalkan fungsi normal bersama. Dari kajian ini, dapat disimpulkan bahawa memakai kneepad akan mengurangkan tekanan pada ligamen lutut pekerja pembinaan untuk mencegah kecederaan dan sakit lutut.

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N	Newton
MPa	Megapascal
%	Percentage

LIST OF ABBREVIATION

FEA	Finite Element Analysis
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Knee is one of the complicated parts in human body. It consists of femur (thigh bone), tibia (shin bone), and patella (kneecap). Femur is the longest bone which is located at the upper leg of human body anatomy so that it can provide a stability for entire body. Tibia is the second largest that located at the lower leg of human body. Tibia bear the body weight in standing and support the motion of the extremities. Kneecap or patella located at the lower end of femur. It protects and cover the knee joint anterior articular surface.

The joints that help in the movements of flexion, extension, medial rotation, and lateral rotation are Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), Medial Collateral Ligament (MCL), and Lateral Collateral Ligament (LCL). The ACL and PCL are responsible for flexion and extension movements. They prevent bones from sliding forward or backward. The MCL and LCL responsible for medial rotation, lateral rotation or abduction, and adduction that prevent bones from sliding sideways.

Figure 1.1: Flexion, extension abduction and adduction of knee

Source: http://cheshireanthropology.files.wordpress.com

Construction works are most common event that required knee to flex, and extend the movements such as kneeling full flexion, kneeling one knee, kneeling 90 degree, squatting, and other positions possible. Figure 1.2 shows the positions of kneeling and squatting by most of the construction workers.

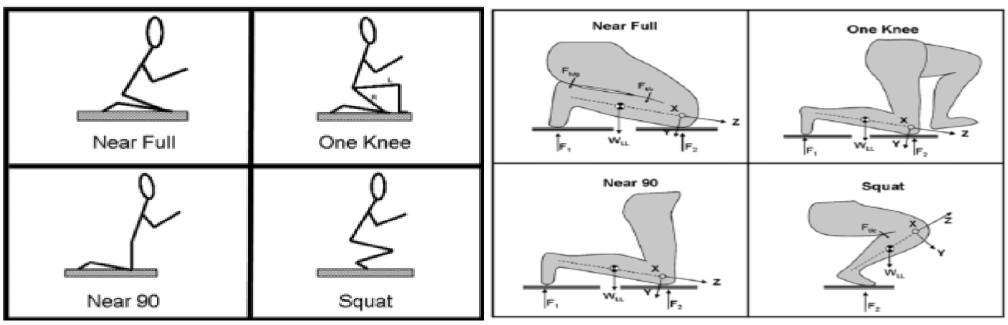


Figure 1.2: Positions of kneeling and squatting

Source: Pollard J.P. et al, (2010)

1.2 PROBLEM STATEMENT

Knee often facing problems when they are experienced the long physical stresses on knee joint. This is because they involves the activities that required to kneeling and squatting that lead to wear and tear of knee joint. Knee also easy to get injured due to its primary functions that support the body weight, flexion and extension movement of the leg. For construction workers, knee injuries occur commonly when they kneeling and squatting for long period and repetitively.

Kneeling and squatting is very common with low-seam coal mining such as doing heavy manual task that can lead to tear and wear of knee joint with extensive exposed to physical stressed on knee joint (Sharrad W. J. W., 1964). The research shows that the common disorder of knee joint injuries of construction workers that caused by long physical stresses of heavy task that requires to kneeling and squatting positions such as kneeling full flexion, kneeling 90 degree, and squatting. In this study, the effects to the ACL, MCL, LCL, cartilage, and patella of kneeling and squatting with and without wearing kneepad is going to be studied for construction workers.

1.3 PROJECT OBJECTIVE

The main objective of this project is to predict the effect of kneeling 90 degree flexion, kneeling full flexion, and squatting by wearing and without wearing kneepad in the terms of stress, and deformation.

1.4 PROJECT SCOPE

The scopes of this project are:

1. 3D simulation of knee consists of femur, tibia, patella, skin, and muscle using FEM software
2. Bones and joints are assumed to be linear elastic and isotropic materials
3. Applying knee joint angle of 90º flexion, 60º flexion, and 130º flexion
4. Applying load are 303N, 603 N, and 900N

5. This study focus on knee joint Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), and Medial Collateral Ligament (MCL), cartilage, and patella

1.5 ORGANISATION OF THE THESIS

The thesis has five chapters;

1. Chapter 1gives the introduction of the thesis; the background study for this project, problem statement of the project, the project objective, and the project scopes.
2. Chapter 2 presents the literature reviews with regards to human knee joint and also the simulation study of human knee. The structure of human knee, some research about construction awkward position and postures, and simulation study also included in this chapter to deep understanding of human knee.
3. Chapter 3briefly presents the methodology of this project. Human knee model developed in different angle of flexion using Solidwork software. The parameters and properties referred from the journals and other research to input the boundary conditions of the simulation.
4. Chapter 4 discussed about the results obtain from the simulation The comparison result between wearing and without wearing kneepad to the knee joint discussed in this chapter.
5. Chapter 5summarizes and concludes the whole thesis. This chapter also identifies opportunities for the future research.

CHAPTER 2

LITERATURE REVIEW

2.1 TYPES OF JOINT

There are three types of joints that classified by their structure: fibrous, cartilaginous, and synovial joints. These joints are also classified by the degree of movement such as synathrodial (immovable), ampiarthrodial (allowing slight movement), and diarthrodial (allowing free movement). Articular cartilage is a soft, and hydrated tissue with 1-5 mm thick that coating the articulating bone. The functions of cartilage is to protect the subchondal bone from mechanical damage, to avoid abrasive wear of bone extremities, and to lower the friction of bone surface. At the end of the bones, a strong but flexible fibrous capsule that encloses the articulating surfaces forms the fibrous joint. Synovium inside the capsule secretes synovial fluid for the lubricant of joint. The collagenous fiber (ligaments) held the joints that resist the tensile force. Ligament at knee joint consists of anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), lateral collateral ligament (LCL), and medial collateral ligament (MCL) (Andy Ransom, 2010).

2.2 ANTERIOR CRUCIATE LIGAMENT

The ACL injuries cause by hyperextended of knee beyond its normal limits, or twisted. Common action that lead to ACL injuries are changing direction quickly, falling off ladder, and jumping from extreme height. It is the most dominant joint to be totally disrupted that occur to young athlete that inducing degenerative changes of the tibiofemoral joint (Pena E. et al, 2005). The ACL is the most frequently injured knee ligament that related to the stability of the knee in multiple direction (Park H. S. et al, 2010).

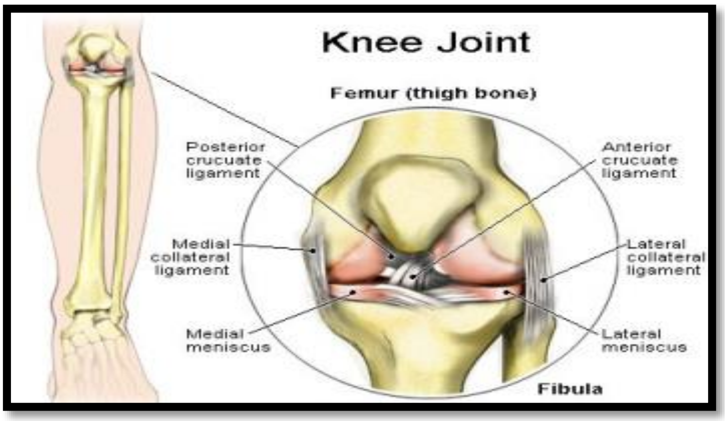


Figure 2.1: The structure of human knee joint

Source: http://www.knee-pain-explained.com/kneeligaments

2.3 POSTERIOR CRUCIATE LIGAMENT

The PCL connects femur bone to tibia bone. The PCL has the ability to prevent femur from moving forward over the tibia. The PCL is one of main injured ligaments in knee injuries due to a blow to the knee while it’s bent. Most common injuries of PCL is caused by athletic, motor accidents, and industrial accidents. The symptoms of PCL injury are swelling, knee pain, trouble walking, and osteoarthritis. The injuries of PCL is very rare, hence the research of PCL is very less. This is because the PCL is twice stronger and thicker than ACL, therefore PCL is less injured (Parvizi J., 2012).

2.4 MEDIAL COLLATERAL LIGAMENT

The MCL maintain the stability of knee by preventing the leg from extending inwards. The MCL is the most injured ligaments after ACL and PCL due to the pressure or stress from outside of the knee that occur concurrently. The symptoms of tear in MCL are knee swelling, pain and tenderness along inside the joint. The MCL is the second stabilizer for human knee after the ACL (E. Pena et.al, 2005). This ligament is more prone to injure than the LCL. The injury is caused by a sudden blow to the outer side of the knee that stretches and tears the ligament at inner side of the knee.

2.5 PATELLA

The function of patella is to protect the articular cartilage of the trochlea and femoral condyles, increase the mechanical advantage of the quadriceps mechanism, and transmit the tensile forces of the quadriceps muscle to the patellar tendon. The patella located at the anterior part of the knee within the tendon of quadriceps extensor muscle (see Figure 2.1).

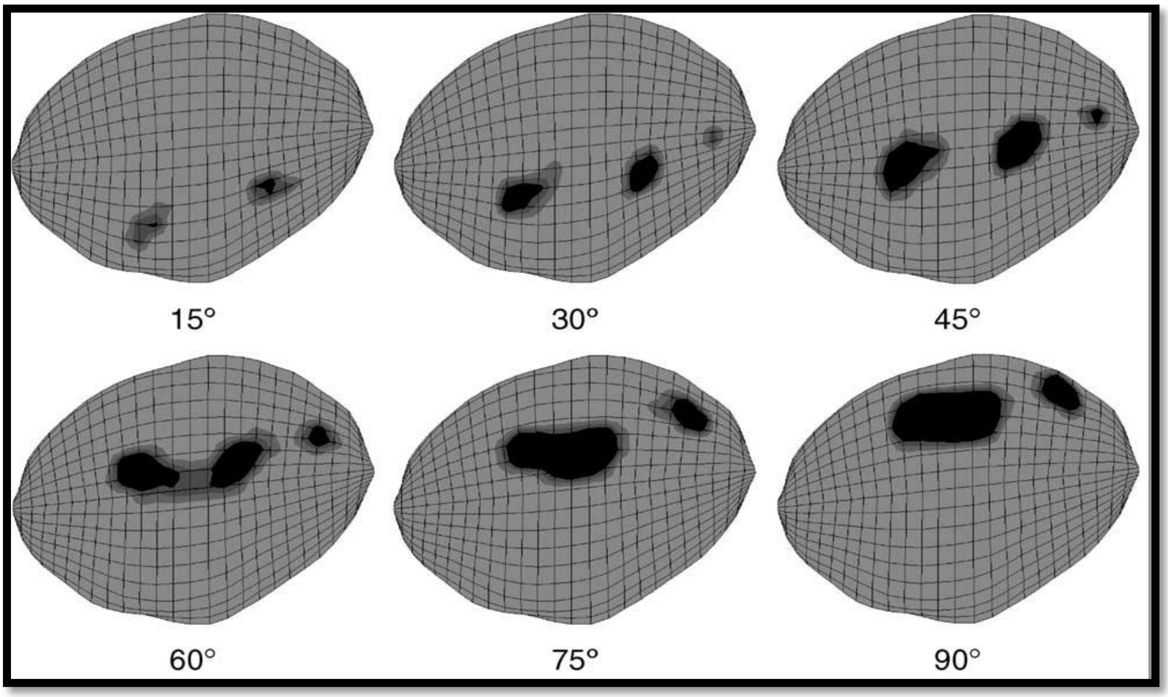
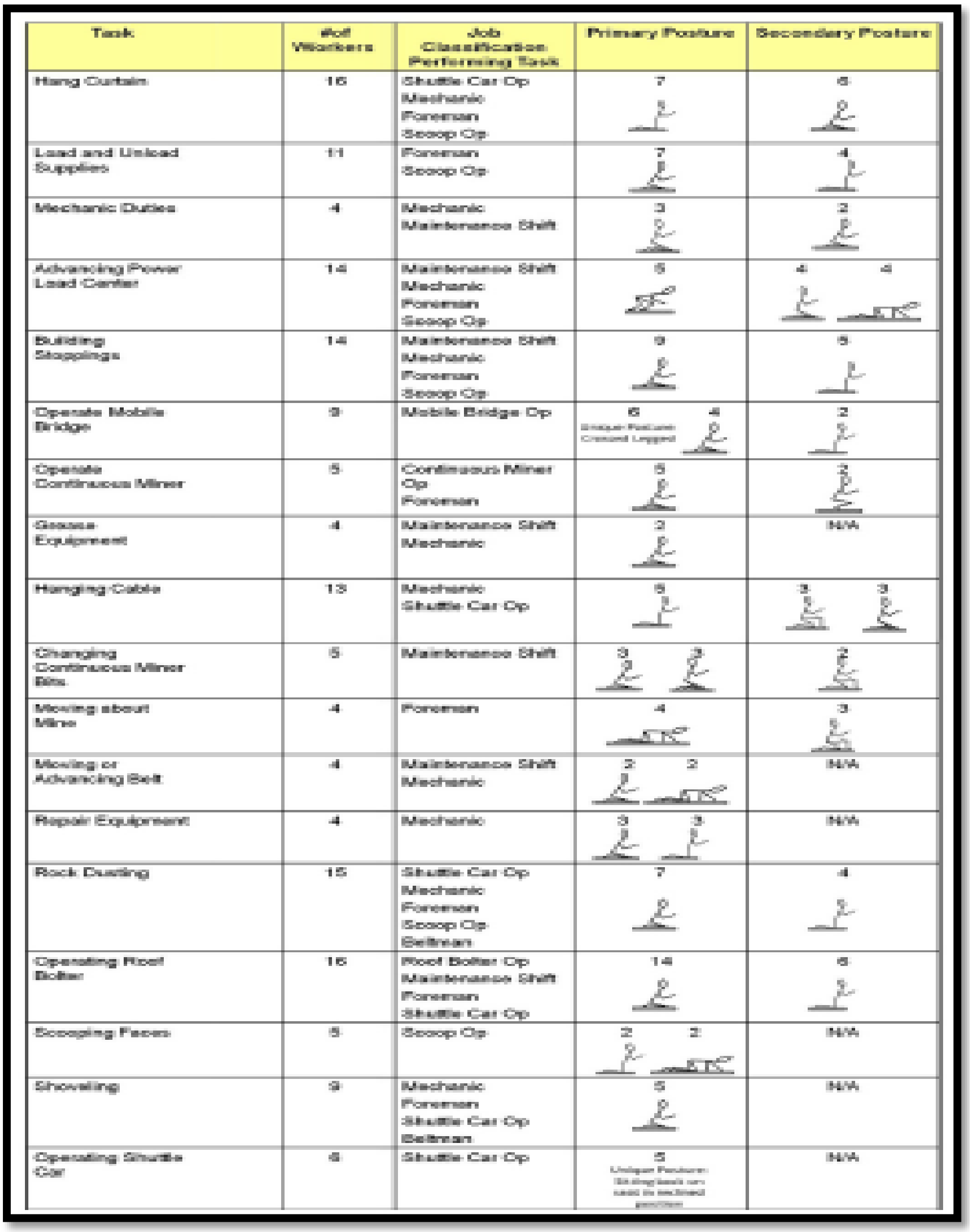


Figure 2.2: The stress at the cartilage layer of patella during knee flexion

Source: Ramaniraka N. A. et al, (2005)

2.6 KNEELING POSTURES

Knee commonly injured at lower extremity in all industries is caused by worker's position and motion. Construction workers have to bear variety of postures according to variety of tasks. The kneeling postures of such as kneeling near full flexion, kneeling 90 degree flexion, kneeling on one knee, and squatting will affect to the knee joint and lead to injury. Common type of knee injuries are meniscal tear, osteoarthritis, ligament tears, and bursitis. All of the injuries occur to low working height worker that require them to kneel and squat (Susan S. M. et al., 2012).



Task	# of Workers	Job Classification Performing Task	Primary Posture	Secondary Posture
Hang Curtain	16	Shuttle Car Op Mechanic Foreman Scoop Op	7	6
Load and Unload Supplies	11	Foreman Scoop Op	7	4
Mechanic Duties	4	Mechanic Maintenance Shift	3	2
Advancing Power Load Center	14	Maintenance Shift Mechanic Foreman Scoop Op	5	4 4
Building Stoppings	14	Maintenance Shift Mechanic Foreman Scoop Op	9	5
Operate Mobile Bridge	9	Mobile Bridge Op	6 Unique Posture: Crossed Legged 4	2
Operate Continuous Miner	5	Continuous Miner Op Foreman	5	2
Grease Equipment	4	Maintenance Shift Mechanic	2	N/A
Hanging Cable	13	Mechanic Shuttle Car Op	5	3 3
Changing Continuous Miner Bits	5	Maintenance Shift	3 3	2
Moving about Mine	4	Foreman	4	3
Moving or Advancing Belt	4	Maintenance Shift Mechanic	2 2	N/A
Repair Equipment	4	Mechanic	3 3	N/A
Rock Dusting	15	Shuttle Car Op Mechanic Foreman Scoop Op Beltman	7	4
Operating Roof Bolter	16	Roof Bolter Op Maintenance Shift Foreman Shuttle Car Op	14	6
Scooping Faces	5	Scoop Op	2 2	N/A
Shoveling	9	Mechanic Foreman Shuttle Car Op Beltman	5	N/A
Operating Shuttle Car	6	Shuttle Car Op	5 Unique Posture: Sitting back on seat in inclined position	N/A

Figure 2.3: The example of kneeling postures for construction worker

(**Source:** Susan S. M. et al., 2012).

Figure 2.4: Kneeling postures of construction worker

(**Source**: W. J. W. Sharrard et al., 1964)

2.7 KNEE INJURIES

Construction worker have to kneel during works and bear the long physical stresses on knee joint can lead to wear and tear of knee joint (W. J. W. Sharrard, 1964). The most common injuries are ACL, MCL, and PCL tears. Tears of the meniscus is caused by acute trauma to the knee. Meniscal injuries are the most common mechanism of a traumatic meniscus tear happen when the knee joint is bent and twisted. Most of the kneeling position by construction worker has the greatest pressure effect at the triangular area bounded by the lower part of the patella proximally with the femoral condyles on either side of it and the tibial tubercle (W. J. W. Sharrard, 1964). Various form of knee injuries suffered by low seam mine worker such as meniscal tears, osteoarthritis, ligament tear, and bursitis have been demonstrated in many studies (Susan M. Moore et. al, 2012). It also shown in previous study that tibiofemoral osteoarthritis has been associated with the frequency of knee bending required at work, frequent squatting, side-knee bending, and sitting crossed legged, and frequent heavy lifting.

2.8 BOUNDARY CONDITION

The boundary condition for the knee is the femur and tibia is fixed (Yuan G. et al., 2009). As for the simulation for prosthetic knee, the prosthetic knee joint was generated by meshing the solid model with 45 brick elements, the tibial component constrained in all degree of freedom and the femoral component was rigidly fixed (Mallesh G., and Sanjay S.J., 2012). Whereas, in knee replacement simulation to evaluate the biomechanical performance of cruciate-retaining high-flexion knee, the boundary conditions are the fixation of femoral component, fixation of proximal end of the quadriceps tendon, and application of ground reaction force (Zelle J. et al, 2009). Each bony structures (tibia, femur, patella), was assumed as rigid body and meshing generation was performed leading to 81 8-node solid element for both medial and lateral tibial articular cartilage, 244 8-node solid elements for femoral cartilage, and 49 8-node solid elements for patellar articular cartilage (Bendjaballah M. Z. et al, 1995). Patella was modelled as rigid body during simulations with 6 degree of freedom and femur and tibia also modelled as rigid bodies but their orientation was fixed to weight- bearing MRI. Cartilage was considered as linear elastic material model due to the elastic response of cartilage during activities that have loading frequencies greater than 0.1 Hz (Besier T.F. et al, 2005). Bones are assumed to be a linear elastic and isotropic material. Knee joint is located between the femur and tibia and material properties of femur, tibia, patella, skin, muscle, ACL, MCL, and PCL were obtained from literature.

2.9 SIMULATION STUDY

Table 2.1: Summary of simulation study

Journal Author	Properties	Simulation	Position		Math modelling	Boundary condition
			Kneeling	Squatting		
S. Checa (2008)		*		*	*	*
S. Farrokhi, et al (2011)		*		*		
Thor F. Besier et al (2005)	*	*		*		
Shunji H.,et al (2000)	*	*	*	*	*	
G. Limbert et al (2004)		*	*	*	*	
E. Pena et al (2006)	*	*		*	*	
Pioletti DP et al	*	*		*	*	*
E. Pena et al (2005)	*	*			*	*
Park H. S. et al, 2010)	*	*		*	*	*
Ying Zhu et.al (1999)	*	*			*	*
Zhang Xu-Shu (2010)	*	*	*		*	*
Yuan Guo, et.al (2009)	*	*				*

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW OF THE METHODOLOGY

This project starts with gathering the information of the Finite Element Analysis on Human Knee. These information are obtained from the literatures and websites that related to the human knee. The literatures are reviewed based on the title of the project. Next, a 3D of human knee in kneeling 90 degree, kneeling full flexion, and squatting are modelled using Solidwork. The parameters and properties for femur, tibia, patella, ACL, PCL, and MCL are used to input the boundary conditions of the simulation. The validation is conducted by running the sensitivity analysis. Then, the simulation is run by using Autodesk Simulation Multiphysics for different angle and different load. The results are analyzed in term of stress, strain, and deformation.

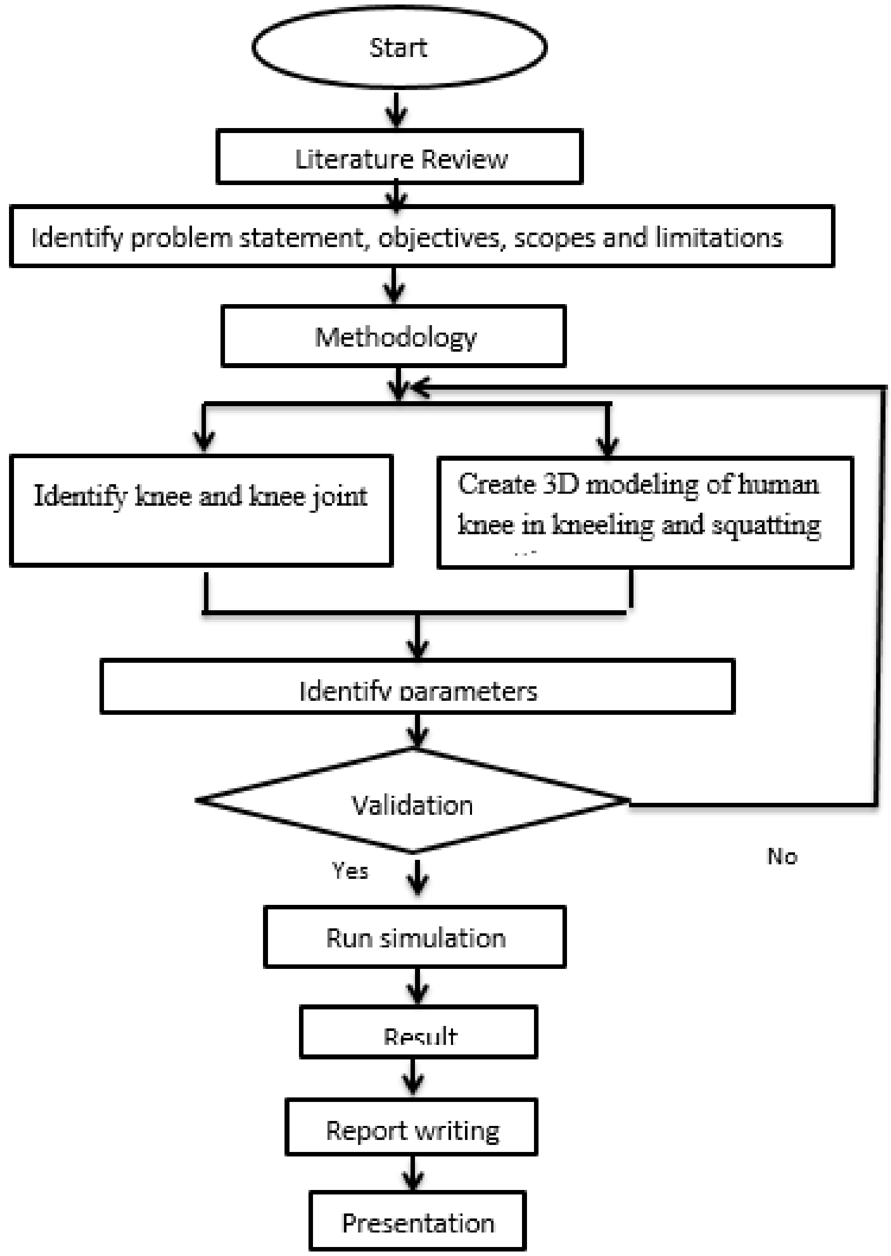


Figure 3.1: The flow chart of human knee simulation