HUMAN SYNOVIAL JOINTS AND MODELLING OF HUMAN KNEE JOINT

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By

OLUFEMI SAMUEL ASHAOLU

In Partial Fulfilment of the Requirements for the Degree of Master of Science in Biomedical Engineering

NICOSIA, 2018

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Approval of Director of Graduate School of Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my parents...

ABSTRACT

In human body, synovial joint has the highest degree of freedom in comparison to other type of joints in the body. This high degree of freedom makes them more susceptible to injuries and might as well lead to disease such as arthritis. These work discuss the types of diseases, various stages of the diseases, then the total replacement of the joint when the disease is at it severe stage. This total replacement does not literally mean the total removal of the diseased joint, but rather the replacement of the diseased articulating part of the joint with an artificial joint which is often refers to as the prosthetic joint. Then finally, the knee joint which is in a critical position and also less protective among all the synovial joint was modeled mathematically using the graphical users interfaces (GUI) of MATLAB software. All the models are being modeled in standing position with a zero degree flexion. It shows how compressive force act on the tibio-femoral joint of the knee at zero degree flexion in standing position. These compressive forces are usually accumulated at the tibio-femoral part of the articulating surface of the knee joint; the vector field of the force was put into consideration.

Keywords: Knee joint; total joint replacement; arthritis; modeling; MATLAB

ÖZET

İnsan vücudunkaki sinoviyal eklem, vücuttaki diğer eklem tiplerine kıyasla çok yüksek bir özgürlük derecesine sahiptir. Bu yüksek derecede özgürlük onları yaralar ve artrit gibi hastalıklara karşı daha hassas hale getirir. Bu çalısma hastalıkların tiplerini, hastalıkların çeşitli evrelerini ve hastalığın ağır aşamasında eklemin yerine konmasını tartışır. Bu yer değiştirme, kelimenin tam anlamıyla, hastalıklı eklemin tamamen çıkarılması anlamına gelmez; bunun yerine, eklemin hastalıklı eklem kısmının sıklıkla protez ek yeri olarak adlandırılan yapay bir eklem ile değiştirilmesi anlamına gelir. Sonunda, sinoviyal eklemin en sık kullanılan eklemi olan diz eklemi MATLAB adlı bir yazılımın grafik kullanıcı arayüzlerini (GUI) kullanarak matematiksel olarak modellendi. Tüm modeller sıfır derece fleksiyonda ayakta durarak konumlandı. Baskı kuvveti ayakta dururken dizin tibio-femoral ekleminde sıfır derece fleksiyonda nasıl etkili olduğunu gösterildi. Bu basınç kuvvetleri genellikle kuvvetin vektör alanı dikkate alınarak diz ekleminin eklem yüzeyinin tibio-femoral kısmında biriktiği göründü.

Anahtar Kelimeler**:** Diz eklemi; toplam eklem replasmanı; artrit; modelleme; MATLAB

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LIST OF ABBREVIATIONS

2D:	Two Dimension
3D:	Three Dimension
CSG:	Constructive Solid Geometry
GUI:	Graphical Users Interface
MIMICS	Materialize interactive medical image control system
PDE:	Partial Differential Equation
PJR:	Partial Joint Replacement
PRP:	Platelet- rich plasma
TJR:	Total Joint Replacement
UHMWPE:	Ultra High Molecular Weight Polyethylene

CHAPTER 1
INTRODUCTION

The human skeletal system is made up of different types of bones which are connected together to form a joint or articulation; these joints are often referred to as the edges which two or more bones meet. Each joint is specialized in its shape and structural component to control the range of motion between the parts that it is connected to. The joints in human body is been classified according to the type of motion which they allow and these classifications are basically in three major types which includes the fibrous joints, cartilaginous joints and the synovial joints (Drake et al., 2009). The fibrous joint is referred to as the immovable joints, these type of joints are held by connective tissue and such joint are usually found in the skull bone, while the cartilaginous joint is referred to as the slightly moveable joints and it is located in the spine or the ribs. Then lastly the synovial joints, the synovial joints are most moveable joint in human body, they make up most of the joints in the body and are mostly located where mobility is critical some can be found in the limbs. They comprise synovial fluid, which helps to reduce friction between the articulating surface; thus, helping them to move freely. Some of them are relatively immobile. Those immobile synovial joints are more stable than the mobile ones which is because of their lesser degree of freedom. Thus the immobile synovial joints are said to be susceptible to lesser risks of injury than the mobile ones. This is as the result of their differences in various degrees of freedom (Drake et al., 2009).

Basically the synovial joint in the human body has been classified into six different types and it is done on the basis of their structures, composition and shapes (Agur et al., 2002). These classifications include, the pivot joints, saddle joints, hinged joints, ball and socket joints, planar joints and finally the condyloid joints.

Planar joints have bones with articulating surfaces which are flat or to a small extent curved, and thus allowing a gliding movement between the joints, there range of movements is limited and does not involve rotation. These types of synovial joints are found in the metacarpal bones in the hand or the tarsal bones of the foot.

Hinge joints are located in the ankle, elbow and knee joints. They are formed between two or more bones in which the slightly-rounded end of one bone fits into the slightly hollow-ends of the other bone, its operation is similar to the hinge of a door, in this way, a bone moves while the other remain stationary.

Pivot joints allow rotational movement only, in pivot joint, the axis of a convex articular surface is parallel with the longitudinal bone axis. Example of such is the proximal radioulnar joint median atlanto-axial joint and distal radioulnar joint.

Condyloid joint, these are the types of joints that allow the angular movement along two axes. Examples are the joint in the wrist and finger which can move on either side to side and also up and down. This is possible because of the oval-shaped end of one bone fitting into a similarly oval-shaped hallow of another bone. Some book authors refer to it as ellipsoidal joints.

Saddle joint, this type of joint also allow angular motion which is similar to the condyloid joint, but in this case, the saddle joint has a greater range of motion. Anatomically, each bones in saddle joints has a concave and convex portion that are fit together, examples of such joint is the thumb joint, the thumb can freely move than the wrist or finger, it has a characteristic of moving back, forth, up and down.

Ball and socket joints have the highest degrees of freedom among the entire synovial joint, it allows movement in all directions. In these joints, one end of the bone possesses a rounded ball-like structure which fit into a cup-like socket of another bone. Examples of such joints are the shoulder and hip joints (Drake et al., 2009). Out of all the synovial joints, the shoulder, hip and the knee has the highest degrees of freedom thus making it more susceptible to the risks of injuries and various level of arthritis, which mainly affects the synovial joint and causes disability (Umich, 2010).

The word arthritis means joint inflammation; arthritis is known to affect joint functionality causing pain and eventually may lead to disability when it progresses from its initial stage to the severe stages. Osteoarthritis and rheumatoid arthritis are the most common forms of arthritis; they occur when the protective cartilage which is also called the articular cartilage that covers the ends of the bones forming the joint wear down over a period of time.

Osteoarthritis is a degenerative joint disease that damage the hyaline cartilage covering the bones thus causing the bone to rob against each other, this cartilage tends to damage due to either trauma, overloading, aging, or genetic disorder which then leads to pain, cracking sounds when joint bends, inflammation or limitation to the patient range of movement ("National institute of Arthritis", 2015). Osteoarthritis might lead the patient to undergo total joint replacement if non-surgical treatment such as medication and physical therapies (therapeutic exercise, electrical stimulation, phonophoresis etc.) all proved abortive. This total joint replacement does not mean that the whole joint will be replaced, rather only the cartilage surface area is replaced with an artificial prosthesis (Standing et al., 2008). Presently, total joint replacement is recognized as an acceptable method of treating severe osteoarthritis and it is a procedure in which part of the damage articulating surface of the joint are replaced with a metal, plastic or ceramic called prosthesis which help to relief pains and helps the patient back to their normal daily activities (Trampuz et al., 2007). These prostheses need to satisfy certain requirement which includes, sufficient static and dynamic strength, ability to absorb energy and shock, biocompatible among others. The total joint replacement can either be according to fixation or type of operation (Pan et al., 2009).

According to American academy of orthopedic surgeon in 2011, almost more than a million total joint replacements were performed in the United State in which the hip and knee replacement are the most commonly performed joint replacement. These joint replacement surgeries can also be performed on other synovial joint such as the ankle, shoulder, wrist and elbow. Total joint replacements are usually faced with some challenges which includes fracture, instability, stiffness, infection and prosthetic loosening, thus the listed challenges lead to the revision surgery for the implant ("American Academy of orthopaedic surgeon", 2011). This revision surgery which fall under the type of operation of joint replacement is used to correct the challenges faced by the prosthesis. Many of these revision surgeries are done within a short period of time after the primary implant procedure. These are very inconvenient and carry a notable risk for the patient. Additionally, it is more painful than the primary implant and also requires longer recovery time.

The knee joint is the most complex and the most important joint in the human body, it made up of two long bones in the skeletal system, these are the femur, also referred to as the thigh bone and tibia, also referred to as the shin bone (Drake et al., 2009). During strenuous activities such as jumping, running and walking, the knee can be loaded as much as seven fold the body weight. The knee joint is a complex of two articulations; a medial and lateral tibia-femoral articulation and patella-femoral articulation. The articulating surface of each bone is covered with hyaline cartilage which is the most important structure of the knee joint because it gives the joint an extremely smooth surface and prevents the underlying bones from damage. Between the tibia and femur forming the joint is a tough fibro-cartilage known as the meniscus, it is a shock absorber inside the knee that help prevent the collision of the knee bones during strenuous activities (Agur et al., 2002). For cases of injuries or osteoarthritis that require knee arthroplasty, the total replacement of knee joint is done by replacing only the worn out surface by artificial prosthesis which is made up of femoral component which is a metals that curved around the distal end of the femur, this possess a groove at the centre of the implant which allows the patella (knee cap) to move up and down when the knee bends or straighten (Rockwell et al., 2011). The tibia component is a flat metal plate with a polymeric plateau placed on it, these polymeric plateau is usually a UHMWPE; which plays a primary role of articulating the metallic component (Math et al., 2006).

The modelling of knee joints is important because it provide information that is too difficult to obtain through experimentation and also create accurate models so that surgical/ rehabilitation procedure can be optimized. These models are meant to solve equilibrium equation of forces and moments from externally applied loads by studying the effect of different component and making prediction about their behaviours. These models can be taken in any form and the example of such forms include; dynamical systems, statistical models, differential equation (partial differential equations PDE or ordinary differential equations ODE) and theoretic model.

Some models required a lot of data for it to be carried out while some requires little data. In the case of models that requires much data, it execution are face with some challenges which includes redundancy and so on. When modelling a system, there are various ways of getting the required data that so as to get an accurate model. These methods of getting data can be broadly classified into primary and secondary methods. The primary method entails the data retrieved first-hand by the researcher via survey, interview and observation while the secondary data gathering methods entail data from a pre-existing source such as records within a system, data within publications and training materials and sources from database or internet, among others (McCaston, 2005).

Basically, the type of data collection methods depends on the type work that wants to be carried out. The major difference between the primary data gathering methods and secondary data gathering method in modeling is that, the primary method is more time consuming in comparison than its secondary counterpart. But still it will enable you to collect data which is specific to the purpose of the modeling. Whereas, if using secondary method, it will tell you what question that is still needed to be addressed and what kind of data that you should collect yourself (Boslaugh, 2007).

Some of the general data gathering methods for joint modeling include:

Experimental Data from cadavers – Mechanical property

SSAM (Statistical Shape and Alignment Modelling).

Some of the modeling methods include the following:

FEM (Finite Element methods)

Rigid multi – body stimulation models

1.1 Thesis Problems

- To defined if computer modelling approach would be applied to develop a mathematical model of the knee joint.
- To determine the force acting on the knee joint at zero degree flexion and examine the part that bears the most loads in the knee joint.

1.2 Aims of the Study

- To review the human synovial joints
- To model the human knee joint in MATLAB using partial differential equation, and to determine the type force acting on the articulating surface; and which part of the articulating surface bears most of the load

1.3 Significance of the Study

- This study will provide information that is too difficult to obtain through experimentation.
- The study will serve as reference to other people conducting a similar study

1.4 Overview of the Thesis

Chapter 1 is an introduction of the thesis, including the thesis problems, objectives, and significance

Chapter 2 focuses on the theoretical background

Chapter 3 presents the anatomy of human knee joint

Chapter 4 describes the materials and methods used in the study

Chapter 5 explains the result and discussion

Chapter 6 concludes the study and also includes recommendations for future studies.

CHAPTER 2
THEORETICAL BACKGROUND

2.1 Total Replacement of Human Synovial Joints

Total joint replacement is an invasive surgical procedure that are effective in relieving joint pain, increasing mobility and improving the patient's quality of life after non-operative treatment have failed to provide such. These total joint replacements are considered to be the last option when it comes to the treatment of synovial joint diseases; this is because it entails total removal of the articulating surfaces of the synovial joint in question. These total joint replacements make use of biomaterials to replace the degenerated living tissue, at times, the biomaterial can cause problem in the living systems because of it in ability to regenerate and adapt to the adjacent tissue.

According to the research done by (Nedoma et al., 2009), they stated that all biomaterial used for total joint replacement must satisfy the under listed criteria;

- Must be unconditional adaptable to the neighbouring materials of living tissues.
- Must have high resistance to bio-corrosion and high consistency against cyclical loading with high initial damping.
- Must have the ability of at-least little regeneration in relation to the neighbouring living tissue, biomaterial with such function is termed to have a higher form of biocompatibility.
- Must be suitable orientation of deformable properties with respect to a type and direction of force function.
- Limitation of total deformation with stress increasing together with the assurance of the elastic behaviour of biomaterials with high local consistency and with minimal necessity of further energy delivery.
- High quality of design on the surface, which make biocompatibility and bio-corrosion impossible.

Ideally, total joint replacement is supposed to be employed when all non-operative procedure has failed to provide relieve for the patient and also when the diseases (arthritis) keep on worsening on a daily basis. Presently, some of these non-operative treatments that are currently available for arthritic patient are usually very limited and they can be grouped as follows:

Symptomatic treatment with simple non-steroidal anti-inflammatory drugs (NSAIDs) e.g. ibuprofen, neptoxen, codine, piroxicam and ketoprofen or intraarticular (IA) injected glucocorticoids and hyaluronic acid (HA) preparations, all these ease the pains and reduce swelling of the affected synovial joints.

Non-pharmacological measures ranging exercise and physical therapy, weight loss.

Surgical joint replacement, these are for severe case, cases in which all the cartilage are loss and none of the above listed non-operative treatment can reduce the pains. Most probably these stages of arthritis can be referred to as the final stage of arthritis.

These stages of arthritis are differing pathogenesis and physical changes. The early stages of arthritis are not easily detected using an imaging device but as it progress, the arthritis joint will demonstrate narrowing of the space between the bones as the cartilage wear out and sometimes deformity of the joint, causing it to look crooked. Basically, the stages of arthritis can be group into four different stage, these will exclude the first stage which is the normal stage (stage 0), because at these stage the joint is seen as been normal and healthy.

Stage 0- Normal

When the joint doesn't show any sign or symptoms of arthritis, it is considered to be at Stage 0, which means that the joint is normal and healthy, with no known impairment or any signs of joint damage. Normal, at this stage of arthritis, no treatment is required for the patient in question.

Stage 1- Minor

At these stages the joint will evolve a very minor wear & tear and bone spur growths at the end of the joints. However, at this stage there are chances of the patient to feel pain or discomfort. The type of pain varies for different individuals. Some individual consider it as pains due to strenuous activities they undergo during their daily routine. At this stage, regular exercise has proved to be useful in treating the arthritis in some patients.

Stage 2-Mild

In Stage 2, diagnostic images or X-rays of the joints will show more bone spur growth; although the space between the bones usually appears normal because the cartilage and soft tissue still maintain its size when healthy. At this stage, there are some symptoms of joint pain (early morning joint pains for rheumatoid arthritis and joint pain after use of the joint for osteoarthritis). Typically, the area around the joints will feel stiff and uncomfortable while doing the normal daily. This stage can also be treated via non-pharmacologic therapies such as exercise, joint support braces and so on.

Stage 3- Moderate

Stage 3, at these stage of arthritis, there are obvious erosion to the cartilage surface between bones are been noticed and fibrillation narrows the gap between the bones, which makes the bones develop spurs at the joints as it becomes rougher. This causes joint pains, popping sounds when using the joint. At these level, simple non-steroidal anti-inflammatory drugs (NSAIDs) of various level are been use by the patients. The variation depends on how it is being responded to by the patient body.

Stage 4- Severe

Stage 4 is considered to be severe. In stage 4 the joint space between the bones are considerably reduced, causing the cartilage to wear off, leaving the joint stiff. The breakdown of cartilage leads to a chronic inflammatory response, with decreased synovial fluid that causes friction, greater pain and discomfort during normal or strenuous activities.

Generally, total joint replacement is considered as the most effective orthopaedic procedures for the severe case of arthritis and these has been in practice for over three decades with an excellent result, except for some microscopic few cases which encounter some complications. Total joint replacement which is also known as total joint arthroplasty can be classified either according to fixation and also the type of operation. According to it fixation can further be classified as either cemented, cementless or hybrid fixation, while for the type of operation, it can either be the primary implant/surgery or the revised implant/surgery (Pan et al., 2009; Brocco et al., 2006).

The history of total joint replacement mostly focuses basically on these three things which are the right materials, fixation and then the bearing surface. Early attempt has used disparate materials such as the ivory, cellophane, skin, pig bladder, plastic, ceramic, glass and metal of various form, surprisingly, many of this did enjoy limited success, but they fail too frequently because they are not biocompatible with the adjacent living tissue in human system in which they are implanted.

Early 1960's, Sir John Charnley developed the first truly successful operation for total joint arthroplasty of the hip, he uses a stainless steel and a polyethylene as a bearing surface (Metal on PE) for the total joint arthroplasty. For many years now, the material chosen in early 1960's by Sir Charnley still remain the Gold Standard for comparison. Although, there has been a trend for modern joint prostheses to employ one of the newer alloy of cobalt-chrome or titanium because these newer alloys are stronger and more corrosive resistance and wear resistance than stainless steel. Currently, because of the increase in the success of the orthopaedic procedures, the early technique has become standardized and joint prosthesis are being implanted in younger patient with greater physical demands than the elderly, thus wear of the bearing surface has become the major problem in current implant technology (Charnley et al., 2005; Learmonth et al., 2007). In younger patient, the strength they exert on the prosthetic devices usually lead to early wear of the device, this is because of the numerous activities undergone by them, thus, for these reasons, there is a need for improvement of the prosthetic device so that the younger generation can benefit from this technological advancement.

There are varieties of bearing surfaces and techniques currently used in an attempt to find a combination that will yield fewer complications so as to avoid constant cases of revision surgeries. This is because these revision surgeries are usually very complicated, painful and also take longer time to heal. For these reason all hands have to be on desk so as to provide a very good and efficient material and bearing surfaces that will reduce the risk of revision surgery after first surgery is done.

Table 2.1: Varieties of bearing surfaces that are currently used in joint replacement

Prosthesis	Advantages	Disadvantage
Metal-on-polyethylene (M on PE)	Cost effective. Low amount of friction. Predictable lifespan.	Polyethylene debris which leads to aseptic loosening of the implanted prosthesis.
Metal-on-Metal (M on M)	Potential longer life due to reduced wear. Lower risk of dislocation.	Metallosis potential. Carcinogenic effect of metal ions.
Ceramics-on-Ceramics (C on C)	Low friction. Low debris particle. It can be polish to a very smooth finish and remain relatively scratch resistance due to it hardness.	Expensive. There brittle nature makes them more susceptible to fracture. The insertion requires an expert so as to prevent early damage. Might produce noise on movement.

2.2 Review of Knee Joint Models

According to the work done by Piotr et al., on the geometrical modeling of knee joint, they modeled a human knee joint using software call the materialize interactive medical image control system (MIMICS) software. This software has a primary function of processing medical image and creating three dimensional models. It uses two dimensional cross-sectional images from computed tomography (CT), x-ray and magnetic resonance imagining (MRI) so as to construct the required three dimensional models which can be linked to Computer Aided Design (CAD), surgical simulation or advance engineering analysis. According to Piotr et al., work, CT was used because of the fact that x-ray pose a limited detriment to human tissues, and also the possibility of CT to fabricate three dimensional model of human tissue via three dimensional image reconstruction (Berman et al., 1987). In their research, the knee was not modeled geometrically in a standing position, it was modeled at 30 degree bending position and it was achieved by placing the knee in a way as to cause a 30 degree bending before the CT detector prior to the examination. There investigation was carried out by the means of helical scans with 1,25mm pitch and 1,375:1 ratio, with an individual scan time of 1second. The power condition of the scan apparatus was 120kv and 300mA, with a beam width that is from 35 to 42mm covering both knee joint (Piotr et al., 2006).

As a result of their CT projection, a sequence image which is a cross section of the bone and muscle was obtained. These images were inputted into the MIMICS software so as to convert the images into a model. The images are usually in a form of triangulated surface mesh file located in the software and these usually consist of image in XY plane (axial image). MIMICS then calculate and create the in sagittal and coronal direction which enables a comprehensive three dimensional reconstruction of the inputted image data. The process of converting anatomical data into a model in this work is called segmentation. During this process (segmentation) of the anatomical knee joint, emphasis are placed more on structures of interest in the sliced of the image data, the filtration of the chosen image range. This information is used to describe the outer surface of the model. Thus an accurate segmentation of the work was ensured so as to extract meaningful information from the image. For this particular work, the accuracy in a MIMICS model matches the accuracy of an image computed within the scan. As a result, if the process gives an undesired effect of sharp edges, it makes working with the model to be difficult.

Another work pertaining to knee joint model was done by David and co; this work is related to three dimensional tibio-femoral internal loading models for total knee replacement. There major aim was to create a computerize knee model which has several inputs such as anatomical data, electromyography data, and computer aided design (CAD) knee implant data which will be use for calculating the internal contact reaction loads on both the medial surface of the knee joint and lateral surface of the knee joint. In addition, their model was capable of being scale on general anatomy, this account for the motion of the tibio-femoral contact, this motion was set as a function of the knee joint flexion angle. The internal contact force output data is a function of flexion angle and it was dependent on the degree of flexion on which the implant designer wants to put into consideration at that time. There model include a graphical user interface (GUI) which shows the internal contact forces on both the medial and lateral aspects of the implant surface which was of help to the implant designer (David et al., 2002).

These researches acclaim to have developed a fully functioning, validated, and documented software package that provides the functionalities described above, but due to redundancy of the muscle network, the graphical user interface output need more literature to be finalized and then a corresponding manual will be written (David et al., 2002).

CHAPTER 3

THE HUMAN KNEE JOINT

3.1 Anatomy of the Human Knee Joint

The knee comprises of four bones which make it one of the largest and the most complex joint in the body. The knee possesses the two longest bone of the skeletal system, which are the femur and the tibia, the smaller bone that runs in parallel direction to the tibia is called the fibula, the patella is the fourth bone that is found in the knee joint. But three out of these four bones meet to create the knee joint; these three bones are the femur, tibia and patella (Nedoma et al., 2009)

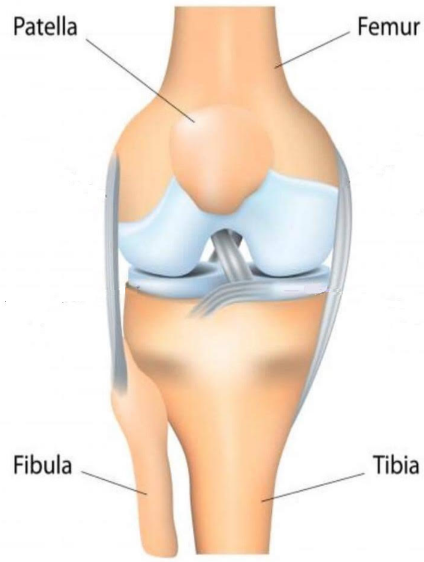

Figure 3.1: Human knee joint (Karadsheh, 2017)

The knee joint articulations formed by these bones are; the medial and lateral tibio-femoral articulation, which joins the tibia to the femur and the patella-femoral articulation which joins the femur to the patella, these two joint articulation work together so as to allow the knee to bend, glide and also to rotate slightly from side to side when the knee joint is flexed (Di-Puccio et al., 2015). Tibio-femoral is the weight bearing surface of the knee joint while the patella-femoral surface allow the tendon of the quadriceps femoris to be inserted directly over the knee, increasing the efficiency of the muscle.

Basically there are three sets of muscle that causes movement, balance and stability in the knee; these are the popliteus, quadriceps and hamstring. Each of these muscles are grouped and each of the group contribute its own part to the movement, balancing and stability of the knee joints (Grob et al., 2016).

Table 3.1: The grouping of human knee muscles

GROUPS	FUNCTIONS	LOCATION	ORGIN	INSERTION
Popliteus	It helps to unlock the knee so as to allow bending of the knee (flexion). Medially rotate the knee.	Behind the knee.	Lateral condyle of the femur.	Proximal tibia.
Hamstring; -Bicep femoris. Semimembranosus. -Semitendinosus.	It is responsible for the flexion of the lower leg at the knee and also extension of the hip.	Posterior region of the thigh.	Ischium.	Tibia & fibula.
Quadriceps femoris; -Rectus femoris. -Vastus medialis. -Vastus lateralis. -Vastus intermedius.	It helps to extend the lower leg at the knee.	Anterior region of the thigh.	Lateral surface of proximal femur.	Tibia.

Apart from the muscles, the other parts of the knee joint are the bones, cartilage, ligament and tendon; these are all made up of connective tissue called the collagen. The bones work similarly to a rounded convex surface sitting on top of a flat surface. The ends of the bone that touch another bone to form a joint are covered with articular cartilage. Articulating cartilage is white smooth fibrous connective tissue that protects the bone as the joint moves and it also allows the bones to move freely against each other. The articulating cartilage of the knee covered the ends of the femur, the top of the tibia and the back of the patella which then makes it to exhibit these type of motion/movement which are:

- Flexion
- Extension
- Lateral rotation.
- Medial rotation

Flexion is the type of movement when the angle between the articulating bones of a joint decreases, these occur when the knee joint is bend. It is produced by the hamstrings, gracilis sartorius and popliteus.

Extension occurs when the angle between the articulating bones is increase, these can occur if the leg is straighten. It is produced by the quadriceps femoris, which inserts into the tibial tuberosity.

The last two, which are the lateral and medial rotation, only occur when the knee is flexed, it is produced by the biceps femoris, semimembranosus, semitendinosus, gracilis, Sartorius and popliteus.

In the middle of the knee are the meniscus (medial and lateral) which sit on top of the tibia and help to spread weight bearing over a larger area and also act as shock absorber inside the knee to prevent the collision of the leg bones during strenuous activities (Sulzbacher et al., 2005).

The ligament are band of strong tissue that are basically use to hold bones to a position, it also gives strength and stability to the knee. These ligaments are strong, tough and are particularly not flexible, it barely returns to its initial position after extension beyond normal limit. The ligament found in the knee joint includes; collateral ligaments (lateral and medial), the collateral ligament of the knee both the medial collateral ligament and lateral collateral ligament help to limit the side to side motion of the knee joint (Saladin et al., 2012).

The cruciate ligaments (anterior and posterior), the anterior cruciate ligament and posterior cruciate ligament of the knee joint are arranged like the letter X of the English alphabets. The anterior cruciate ligament limit rotation and forward movement of the tibia while posterior cruciate ligament limit the backwards motion of the knee. These four ligaments working together are the most important structure in controlling the stability of the knee. The knee structure doesn't have much protection against trauma and force/stress, due to these reasons, a lot of complications such as injuries which are of various kinds and also osteoarthritis of the knee joint might be caused. According to most of the articles from Arthritis Foundation, arthritis related problems such as osteoarthritis and rheumatoid arthritis are second after heart disease as the leading cause of any nation losing it workforce (Setton et al., 1998).

Although knee problem is often caused by injury to any of the structure or part of the knee joint, it can also have other causes which might include: sport, recreation activity, getting old, daily jobs or having a disease such as osteoporosis or arthritis which increases the chances of having knee problems. Injuries and arthritis are the most common problems that the knee joint is facing. Injuries such as fracture, dislocation and ligament tear are mostly caused by abnormal twisting and bending of the knee, direct blow and falling on the knee ("Modules", 2017), in the case of arthritis which is a degenerative joint disease, it's often refer to as a chronic disease that affect the joint and the most common type of arthritis are the post-traumatic arthritis, osteoarthritis and rheumatoid arthritis.

Post-traumatic knee arthritis is suffered by million around the world, this as a result of a serious knee injury (fracture of the bone that surrounds the knee joint or tearing of the knee ligament) which leads to the damage of the articulating cartilage of the knee over time. The symptoms of post-traumatic arthritis are very similar to that of osteoarthritis and it includes swelling, severe pains and sometimes internal bleeding (Leonardo et al., 2007).

Unlike the post-traumatic and osteoarthritis of the knee joint, the rheumatoid arthritis of the knee joint is a systematic disease of the immune system that causes the joint to be stiff, painful, warm and The cause of rheumatoid arthritis is not fully understood, although some believed that abnormal response of the immune systems plays a major role, but none is known why the immune system goes away. It can also be linked to genetic and environment factor as its causes swollen. It occurs when the immune system attacks the synovium (the lining of the membranes that surround the joint), this inflammation causes

the synovium to be thicken which in result destroy the articulating cartilage and the bones within the joint. The common symptoms of rheumatoid arthritis are:
Pains, swollen joints and warm, these occur in the both knee, this is because rheumatoid arthritis is a symmetry disease. Fatigue, flu-like symptoms, weight loss and fever, because it is an immune disease.
Joint stiffness; which is usually very severe early in the morning or after inactivity of the joint for a long period of time.
Osteoarthritis is caused by a multitude of factors, which have not been completely explored and understood. However, some of it basic factors include: obesity, improperly repaired meniscus tear, aging, genetic disorder, overloading of the joint, weak thigh muscle and so on ("Atlas of Osteoarthritis", 2015). Osteoarthritis of the knee joint can be easily detected by taking historical records of the patient in question and also doing some physical examination such as:

- Squeaking or grating sound
- localized enlargement
- excess fluid
- reduced movement
- joint instability
- muscle thinning
- Joint tenderness.

And also using an imaging technique such as the X-ray which may shows changes such as bony spurs or narrowing of the space between the bones. It will also show whether any calcium has settled in the knee joint. The magnetic resonance imaging (MRI) scan is barely useful, because it only shows the soft tissues (cartilage, tendons, muscles) and changes in the bones that can't be clearly view on a standard x-ray. It main use is to look for another joint or bone problem in someone who doesn't have the normal symptoms of osteoarthritis on the knee joint. The laboratory test for knee diagnosis is not of much relevant, but it is done so as to rule out other types of arthritis that are present in the bone.
Osteoarthritis does not evolve uniformly, for now it is difficult to generally predict how fast the evolution of osteoarthritis will be. This is because, in some cases it progresses

slowly over a period of many years and in other circumstances, it can develop quite rapidly, making it unpredictable and also create these imbalances between pain and radiographic image of the disease. For these reasons, the evolution of osteoarthritis is difficult to understand and evaluate. Presently, the severe case can only be treated but can't be totally cured.

Generally, there are various treatments which can be administered to the knee joint so that some of the complications faced by knee joint are avoided. These treatments usually depends on what exactly is causing the problem, the treatment include; medication, therapy and injection (Naguro et al., 2006).

Medication usually help to relieve pain symptoms and treat underlying conditions, then therapy strengthen the muscle around the knee which makes it more stable. These therapies might include physiotherapy, exercises such as easy cycling, and swimming, walking longer distance and so on. While injection which is probably the last one, in these cases, substances such as platelet-rich plasma (PRP), hyaluronic acid or corticosteroids are directly injected into the knee joint. These injections are not that reliable because it effective validity in the knee can't exceed the can maximum of six months so it tends to make the process a repetitive process.

In advance stages of these condition, if few conservative treatment as listed above is not effective, the only option may be the knee surgery. There are various types of surgeries that are performed to the knee joint, these surgeries include the total replacement of knee joint, patella resurfacing/ patellofemoral replacement and the partial replacement of knee joint. The most common of these surgery is the total joint replacement of the knee, which is the replacing of the joint surface at the end of the femur (thigh bone) and the joint surface at the top of the tibia with an artificial prosthesis (Sulzbacher et al., 2005). Other forms of knee surgery are the partial knee replacement and the kneecap replacement.

The partial knee replacement can be carried out if the osteoarthritis affects only one side of your knee and the patient in question has a strong knee ligament, then these proceeds is advisable. The partial knee replacement can replace either the inside (medial) part of the knee or the outside (lateral) part of the knee. It is possible to have a half-knee replacement (sometimes called uni-compartmental or partial replacement). It has a quicker recovery ability and better function when compared to the total joint replacement. This is because it can be carried out through a smaller incision and the underlying muscles are minimally disrupted than a total knee replacement, using techniques called the reduced invasive or minimally invasive surgery.

Figure 3.2: Partial replacement of the knee joint ("Knee Joint" 2017).

The kneecap replacement is done by replacing under-surface of the kneecap and its groove (the trochlea) if these are the only parts affected by osteoarthritis. This is also called a patellofemoral replacement or patellofemoral joint arthroplasty. The operation has a higher chance of failure than total knee joint replacement; these failures might be caused by the arthritis creeping to other parts of your knee. However, the outcome of kneecap replacement can be good if the arthritis doesn't spread to other part of the knee after surgery. According to literatures, single patients out of 40 patients with osteoarthritis are suitable for patellofermoral joint arthroplasty. For these reason, more research is needed to understand which people are likely to do well with this type of joint replacement.

Total replacement of the knee joint; in total replacement of knee joint, the arthritic or injured joint surface are remove and replaced with artificial knee joint which is often called the prosthesis. These prostheses which are also referred to as the artificial knee joint replacement can be divided using many factors, these factors includes:

According to construction system: which can either be with a movable part or without a movable part.

According to it fixation: these can be either cemented fixation, cementless fixation or the hybrid. This hybrid fixation is the combination of both cemented fixation and cementless fixation. It is basically done by cementing a part of the prosthesis to the bone and then leaving the other part as uncemented, allowing bone to grow into the prosthesis. Example of hybrid fixation is done by uncementing the femur with a cemented tibia and patella and vice-versa.

According to indication: primary and revised.

According to type of tibia plateau: the tibia plateau which serves as the bearing surface can also be either fixed or mobile, depending on the choice of the patient or surgeon handling the patient. A fixed plateau means that the prosthesis has a fixed bearing surface, while a mobile plateau means that the prosthesis has a mobile bearing (Pan et al., 2009).

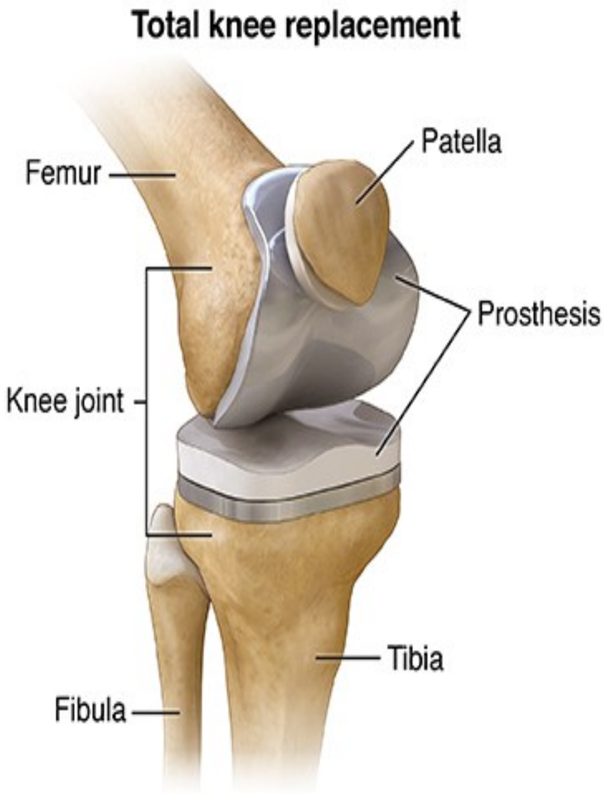

Figure 3.3: Total knee replacement ("Total Knee Replacement", 2017)

Looking from the statistic of various manufacturer across Europe, we can say that, metal to polyethylene are the most commonly designed bearing surface for total knee joint replacement, and the bearing can either be fixed or mobile bearing surface depending on the demand. In the case of the fixed bearing, the polyethylene cushion of the tibia is fixed firmly to the metal platform base, then convex surface of the femoral roll over the cushion making it provide a good range of motion. The fixed bearing surface is commonly among orthopaedic surgeon for their patient. But in some cases where the patient is young, vibrant and also susceptible to excessive activity or extra weight from an obese patient, then the mobile bearing surface is considered by the surgeon (Affatato et al., 2010).

The difference between these fixed and mobile bearing surfaces is that polyethylene insert in the tibia component of the mobile bearing surface can rotate a short distance inside the metal tray, therefore in designing the mobile bearing surface, the designer put into consideration the fact that, the natural knee flexion involves about 20° of external rotation of the femur on the tibia. This rotation allows patients a few degrees of greater rotation to the medial and lateral side of the knee (Abdel-Rahman et al., 1998).

The general procedure for knee replacement has be categorize into four basic steps by the American Academy of Orthopaedic Surgeon

Bone preparation; the damage articulating cartilage caused by arthritis at the end of the bones (tibia and femur) are removed along with a small amount of bone beneath the articulating cartilage. Small bones are being removed with the cartilage so as to take off some part of the affected bone. This might also reduce the cause of revision surgery by a little fraction.

Position the metal implants; the second step is by replacing the diseased joint that is cut out with metal components so as to recreate the surface of the joint. These metal parts been implanted can be done via; cementing or press-fit (un-cementing) into the bone.

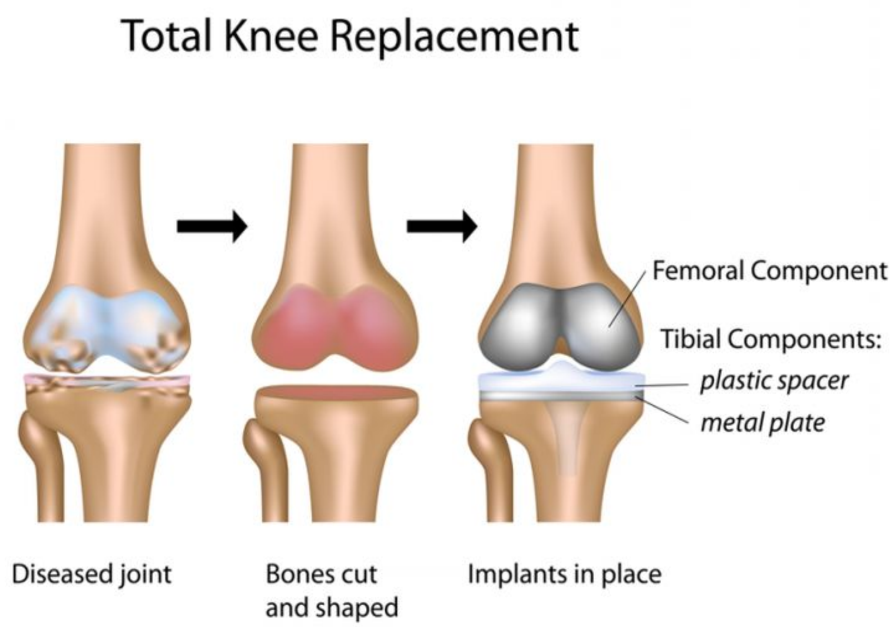

Figure 3.4: Procedure for knee replacement ("Total Knee Replacement", 2017)

Resurfacing of the patella; the under surface of the diseased kneecap which is also refer to as the patella is then cut and resurface with bearing material. For the case of metal-on-polyethylene, UHMWPE in form of a plastic button is the one commonly used. In some case, the surgeon doesn't resurface the patella but this is for only some selected case in which the patella is not diseased.

The spacer inserts; a plastic spacer of UHMWPE material is place on the tibia plateau so as to separate the metal component of the femur bone and tibia bone. The plastic spacer allows articulation of the surface in terms of gliding and some few degree of rotation in some cases.

CHAPTER 4
MATERIALS AND METHODS

4.1: Mathematical Modeling of Human Knee Joint

Basically the knee joint is the most used joint in human body and a minor problem to the knee joint; most probably will affect a person's day to day activities. These are because of the role knee joints plays in human locomotion and also that the knee is an important load-bearing joint and it importance can never be under estimated. The knee joint is considered the largest weight-bearing joint [American Academy of Orthopedic Surgeon] and also the most complicated joint in the human skeletal system. This complication can either be in term of it composition, function, geometry or set-up.

According to (Nedoma et al., 2009) the whole body weight and external load acting up on a body are usually transferred into the bone tissue. Bone tissue is also referred to as osseous tissue, this bone tissue specifically refers to the bone mineral matrix which forms the rigid section of the bone that make up the human skeletal system (Saladin et al., 2001). For the case of the knee joint, the force acting on the joint is been transfer to the articulating surfaces of the knee joint. These articulating surfaces of the knee joints are the medial tibio-femoral and lateral tibio-femoral, then the patella-femoral articulating surfaces. This force acting on the knee joint is derived from the body mass above the knee that is acting through the thigh (Paul et al., 2009).

The forces acting upon the knee joint are usually estimated towards the articulating part of the knee joint by either using a direct measurement via instrumented knee prosthesis or mathematical modeling (Nagura et al., 2006). During standing, normal working and cycling, the force that is transmitted across the knee joint is 2 to 3.9 times the body weight, while 5 to 6 of the body weight is transmitted to the knee during squatting up and down. According to the work by Kuster, they also estimate that during strenuous activities such as running and so on; the knee joint is usually loaded with 7 times the body weight. All these are compressive forces that act downward on the tibio-femoral articulating surface of the knee joint (Kuster et al., 1997; Smith et al., 2008).

This study has an objective to model the knee joint using software called MATLAB. The software incorporates mathworks and makes it the building block of MATLAB; the need of data gathering scientist can be negligible when using nearly all the recent software for modeling. For this case, the femur and the tibia are modeled geometrically as two rigid bodies as shown in Figure 4.1. In this case, the cartilage deformation is relatively small and it is not affected by relative motion and forces within the tibio-femoral articulation, so it will be neglected in the modeling process.

4.2: Methods

Using the constructive solid geometry modeling (CSG model), the geometrical image of the knee joint was drawn as two different rigid solid body, the femur and the tibia (Polyanin et al). The fibula and the patella were not considered for these particular studies. The geometrically modeled femur is a polygonal in shape and the tibia a flat rectangular surface. Pictorially the geometrical modeled knee joint looks like a sectional part of the human knee. The set equation generates from the software for this model is P1+E1+E2+R1.

Because of the irregular shape of the knee joint and it unavailability on the default set up of the software, the geometrical model of the knee joint is usually very difficult to design and control shrewdly. So for this reason, the femur is considered as a polygonal shaped object in the CSG model and the tibia a flat rectangular surface. From the anatomical description of the tibia plateau, it is considered as a flat surface in which the condylar of the femur glide and slide so as to cause dynamic loading and motion.

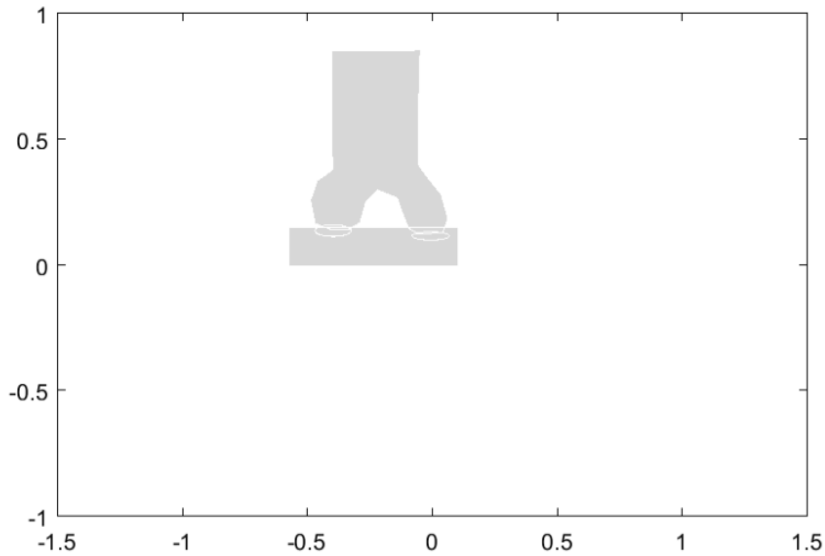

Figure 4.1: Two dimensional PDE mode image of a knee joint in a standing position at zero-degree flexion; using the constructive solid geometrical model

The knee is model in a standing position at 0-degree flexion; thus the polygon which is representing the femur stand at 180 degrees on the solid rectangular object representing the tibia in the CSG model. The set equation generates form the above model is P1+E1+E2+R1. Then the following assumptions where then made:

Rotation in the knee is not considered for the study.

The tibia is a flat surface which is not moveable in respect to the motion of the femur standing on it.

The femur was considered at standing position; on the tibia plateaus at 180 degrees in the geometry.

The fibula and the patella are not considered for this study so they are not included in the geometrical setup of the knee.

Abnormal cases such as Valgus and Varus was not put into consideration for the purpose of this work.

Condyles of the femur were put into consideration because of the CSG model.

We assume natural boundary conditions for the entire geometrical model; thus, on MATLAB software, Neumann boundary condition at default stage was used.

The equation of stress-strain distribution in the bone was used.

Considering the above assumption; two solid rigid bodies where model on the CSG model in the Graphical user interface (GUI) of partial differential equation tool (PDE tool) which is an application in MATLAB software.

The 2-D image of the knee was constructed using some out of the four basic solid objects that are available for construction in the constructive solid geometry model (CSG model). The CSG is the only device that can be use to geometrically design a model in the toolbox of partial differential equation of the MATLAB software. Basically for this work, polygon and a rectangle from the CSG where then used to create a sectional part of the human knee joint under study. The geometrically modeled knee joint has it condyle which is the articulating part that is comfortable sitting on the flat rectangular tibia in zero-degree flexion; thus, it forms an angle of 180 degrees for a normal case. But for abnormal cases such as the valgus and varus deformities, there is a little deviation from 180 degrees according to the research done by (Biagio et al., 2015).

According to the research carried at by Biagio et al. (2015), on how to access the lower limb alignment via comparison of standard knee X-ray versus long leg view. They arrived at a conclusion which is in agreement with current available literature; the gold standard use for the measurement of knee alignment is represented by the mechanical axis of the lower limbs.

These can be measured on full length weight bearing x-ray of the leg in standing position; for Biagio et al. (2015), studies of different cadaver knee, and it outcomes was:

Valgus alignment which is generally refer to as K-leg in the layman's language will be greater than 180 degrees with a mean value of 0.93 degree for group of people under study.

Varus alignment which is generally refers to as bow leg in layman's language will be less than 180 degrees with a mean value of 0.73 degree for the group of people study by (Biagio et al., 2015).

Currently this is the gold standard for measuring knee alignment and its outcome tally with a lot of literature.

After constructing the 2-D geometry of the knee using the CSG model, the boundary conditions are defined. For this model there is no boundary condition because the original shape of the two solid object that forms this model consist of border between the subdomain of the model

The next step to be taking is the definition of the partial differential equation. At this stage, the equation that is supposed to be used for modeling of mathematically force are usually defined and inputted into the PDE coefficient. For our study, the equation we used was the equilibrium equation of stress-strain distribution in the bone.

$$\frac{\partial \tau_{ij}}{\partial x_j} + f_i = 0. \quad (4.1)$$

$$\tau_{ij} = c_{ijkl} e_{kl}(u) \quad (4.2)$$

$$e_{ij}(u) = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (4.3)$$

i, j, k, l = 1………… N = 2

The boundary condition for the equation of stress-strain distribution in the bone will be the evaluated with this equation, the weight bearing part

$$\tau_{ij} n_j = p_i \quad (4.4)$$

Where

$r_\tau = 1r_\tau \cup 2r_{\tau.}$

Where,

$1r_\tau$ - Is the weight bearing part of the knee joint in the model.

$2r_{\tau.}$ - Is the second part of the bone where force doesn't exist and it is taken as zero in the model.

Where r_τ is the displacement boundary condition of the model, this can also be used for simulation and modeling of human joint.

From the four default partial differential equations (PDE) in MATLAB software toolbox;

$$-\nabla.(c\nabla u) + au = f. \quad \text{-------- Elliptic Equation} \quad (4.5)$$

$$d\frac{\partial u}{\partial t} - \nabla.(c\nabla u) + au = f. \quad \text{-------- Parabolic Equation} \quad (4.6)$$

$$d\frac{\partial^2 u}{\partial t^2} - \nabla.(c\nabla u) + au = f. \quad \text{-------- Hyperbolic Equation} \quad (4.7)$$

$$-\nabla.(c\nabla u) + au = \lambda du. \quad \text{--------Eigenvalue Equation} \quad (4.8)$$

Elliptic and parabolic partial differential equations are the ones use for modeling purpose; these modeling can be either distribution of stress applied on the bone, steady and unsteady heat transfer, potential flow, steady state of waves, diffusion problems, flow in porous media and many more. The partial differential equations toolbox provides a lot of system in which all these can be solved; these include; generic systems of PDEs, structural mechanics – Plane stress, electrostatic, structural mechanic – Plane strain, diffusion and many more.

For the purpose of this work, elliptic equation is use;

$$-\nabla.(c\nabla u) + au = f. \quad (4.9)$$

The mathematical equation in which the parameter will be inputted as the PDE coefficient is the equilibrium equation of stress-strain distribution in the bone;

$$\frac{\partial \tau_{ij}}{\partial x_j} + f_i = 0 \quad (4.10)$$

i, j, k, l = 1.

$$\tau_{ij} = c_{ijkl} e_{kl}(u) \quad (4.11)$$

$$e_{ij} = \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (4.12)$$

The elliptic equation can also be written as

$$-\nabla.(c\nabla u) + au = f. \quad (4.13)$$

Can be rewritten as

$-(c\nabla^2 u) + au = f.$ When the bracket is expanded (4.14)

To equate it with the stress- strain distribution in bone at equilibrium

$$\frac{\partial \tau_{ij}}{\partial x_j} + f_i = 0 \quad (4.15)$$

$$c\nabla^2 U - au + f = 0 \quad (4.16)$$

Where

$$\tau_{ij} = c_{ijkl} e_{kl}(u)$$

$$e_{ij} = \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

∇^2 U = $\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$ in two dimensions

Then

$$-c\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+au=f \qquad (4.17)$$

The weight bearing part of the knee joint that is consider for this study is the tibiofermoral and it is denoted by r_τ.

The load acting on the geometrical modeled knee joint is denoted by the y (u) load in the PDE tool box parameter.

All the models are modeled in standing position at zero-degree flexion; which is at 180 degrees on top each other. But for the cases of valgus and varus, there is a little deviation from 180 degrees.so for these particular studies, valgus and varus are not put into consideration. All cases considered are for normal knee joints. The magnitude of the applied load varies from 1470N to 2060N for each of the geometrical model. This load is acting directly downward on the femur head which lies on the tibia plateau. And the value young modulus from the software was change from 1.7E3 to 2.1E3.

From each of the geometrical model, we formulate the nodes acting and the meshes where the compressive force acting is concentrated by repeatedly jiggling the initial mesh. Then this was plotted in a 2D graph all via the MATLAB software.

CHAPTER 5
RESULT AND DISCUSSION

Geometrical image where constructed for the knee joint all in a standing position when a force of 2000N is act upon the knee joint. This force is usually concentrated in the tibio-femoral articulating region of the knee joint; tibio- femoral articulating region is use for loading on the knee joint. It was determined that the force acting is a compressive force which tends to act downward toward the region of articulation of the tibio-femoral joints. The contact stress from femur condyle is then been transfer to the tibia. The compressive force causes a dark pigmentation on the modeled knee joint. This pigmentation is a result of the concentration of the compressive force which is acting downward in the model. In real life, it can lead to the loss of cartilage on the surface of the tibia and femur, thus causing osteoporosis, osteoarthritis and so on.

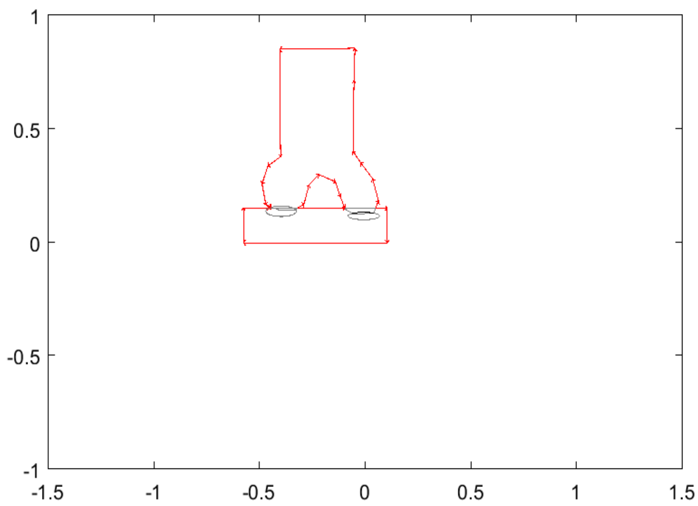

Figure 5.1: The boundary mode of a two dimensional knee joint model in standing Position at zero-degree flexion. This was design using the Graphical user interface model in the MATLAB software.

At this boundary mode, the equilibrium equation of stress-strain distribution was not yet applied to the geometrical model. It show how the domain intercept with each other by default, thus there is no force acting in this conditions.

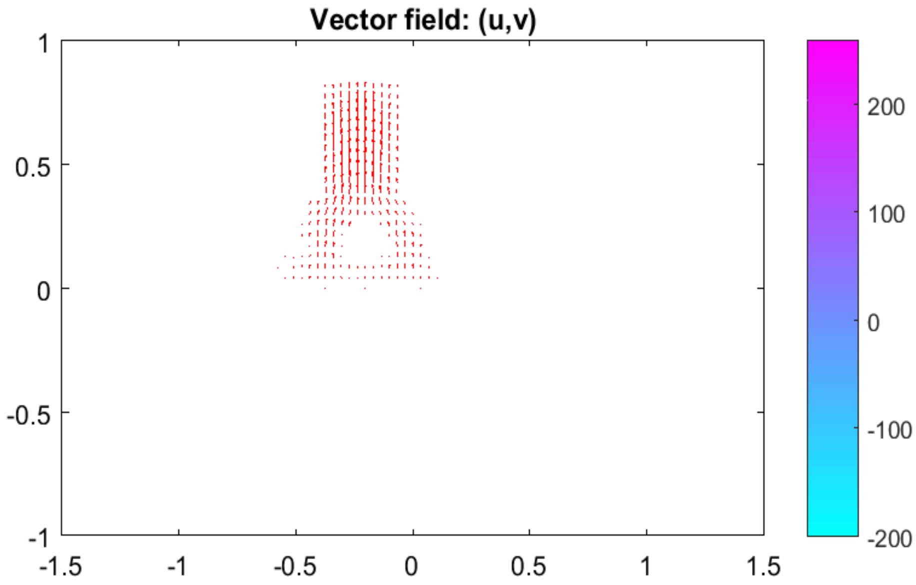

Figure 5.2: The vector field of a human knee joint model. This was modeled in standing position at zero-degree flexion and a force of 2000N is acting downward the femur.

Vector field is the assignment of a vector to each point in a subset of space and it can be viewed as the collection of arrow with a particular direction and magnitude. Vector field is usually use to analyses certain result whose input is directly proportional to it output in terms of dimensions. Thus it is indicated by the vector arrow which usually indicates the magnitude of the direction of force. This force which is a compressive force that tends to apply pressure, power or exertion at the point of articulation of the knee joint, the point of articulation in the knee that bears the most loads is the tibio-femoral articulation thus the force causes the squashing of the underlying cartilage.

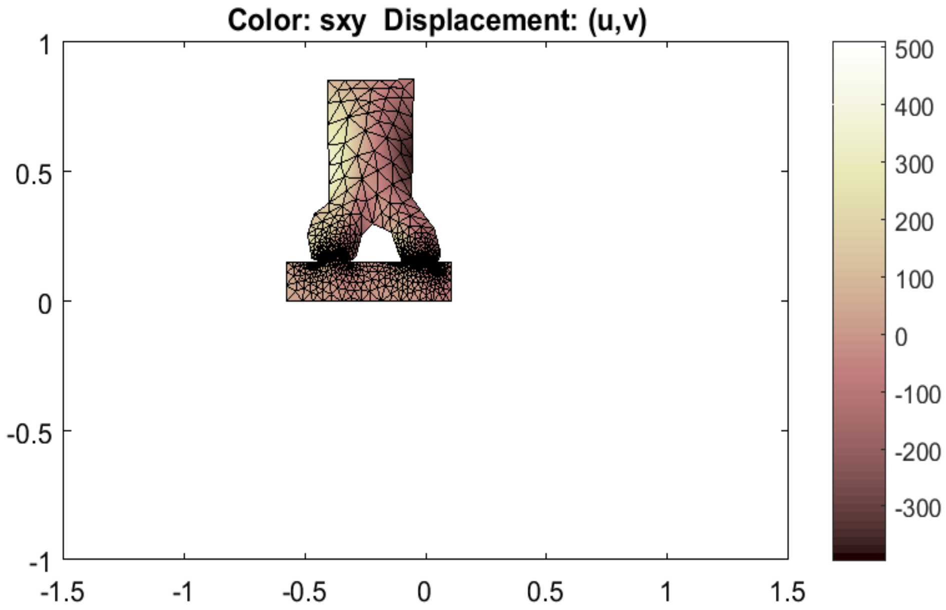

Figure 5.3: Two dimensional geometrical model of the knee joint at standing position with a zero-degree flexion using the GUI in MATLAB; the model is showing the shear stress distribution in the joint.

From the shear stress graph above, it can be said that force tending to cause deformation of the rigid material which is the tibia, the tibia that lie beneath where the stress is coming from, which is the femur. It is clear that as pressure causes compression, we can also say that shear stress causing shear. This shear stress tend to deform a material without any change in volume of the material, from the figure above we can see how the deformed area of the material is darken and squeezed.

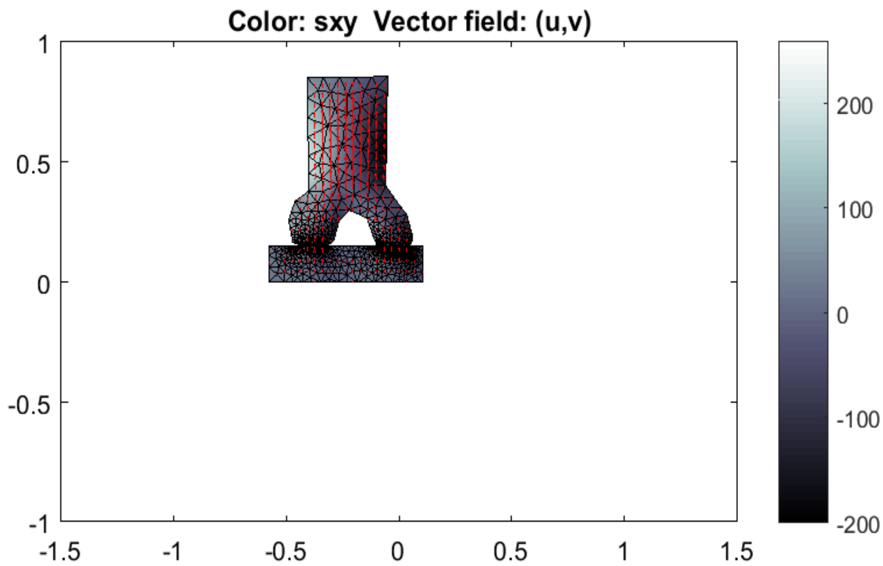

Figure 5.4: Two dimensional geometrical model of the knee joint showing the vector field and shear stress that is acting on the model.

The stress distribution is not uniform across all the cartilage, so from the diagram we can see why some part are more jingled than that the others. If the load that was distributed was uniform over the cartilage, the concentrated load tend to act over a small area which result to high localized stressed and also non uniform stress distribution. This is why the deformation of the hyaline cartilage is irregular despite a uniform stress coming from the femur bone.

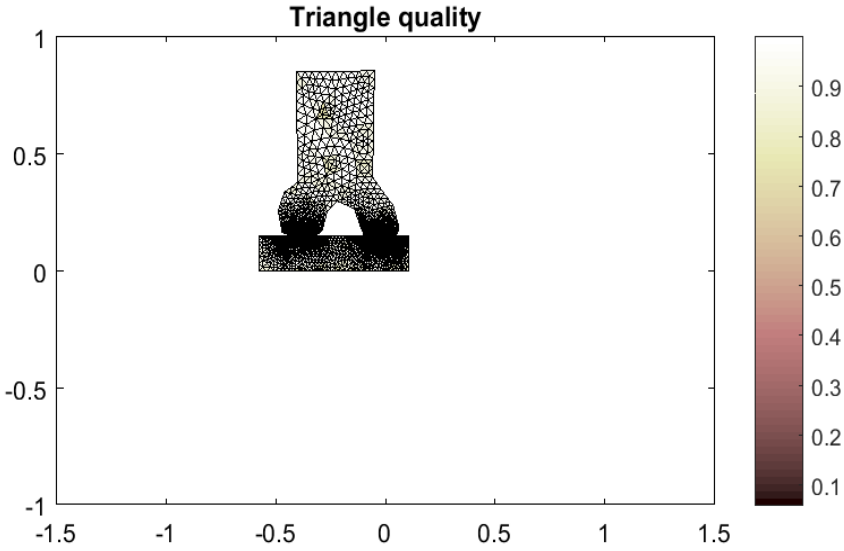

Figure 5.5: Triangular quality measurement of the modeled two dimensional knee joint.

From the graphs of the all the results, it shows that the forces that are transfer in the femur bone usually move down to the articulating part of the knee joint; where the condyles meet the tibia. The articulating part under consideration here is the tibio-femoral articulating surface of the knee joint. These study of forces transfer in the knee joint are of great clinical significant. The motive of creating these MATLAB model is to have a better knowledge of the in vivo of the knee behavior and then improve the knee design afterward. The knee forces have a firm basis in reality and have a meaningful impact on joint degeneration, injuries and arthritis (rheumatoid arthritis and osteoarthritis). Among the importance of such force includes the following:

It provides the designer with an accurate understanding of the load and how it is distributed so as to effectually analyses the force and prevent their failure modes.

It provides clinician with a quantitative amount of data so as to decide which kind of treatment is suitable for the prevention and treatment of knee disease such as rheumatoid arthritis and osteoarthritis.

It provides enough information for the design prostheses that will be used for total and partial replacement of human knee joint.

It helps in showing an important mechanism for potential injury and knee rupture

It can be used to derive computer model that can predicts outcomes which can be used for in-vivo measurement of factors such as;

Stress distribution.

Wear of articulation surfaces.

Degree of damage of the bones in contact.

It is also said that mechanical loading (static or dynamic loading) as of such in this study is said to play an important role in the origin, development and progression of arthritis. So, these model will provide provides a strong impetus for the development of accurate stress-strain analyses for total joint replacement (Nedoma et al., 2009).

These stress-strain distributions from the above work tell us that the compressive force acting downward from the femur to the tibia is moderately distributed on the top of the tibia plateau in a case of 0-degree flexion of the knee joint.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

A knee joint was modeled mathematically using the stress distribution equation at equilibrium; this modeling was done at 0-degree flexion in a standing position. From this study, we can conclude that the tibio-femoral part of the knee joint is the point at which the load acting on the knee joint is concentrated. And the type of load acting is compressive forces which act from the femur to the tibia plateau. And excessiveness of such force causes osteoporosis, osteoarthritis among other joint diseases which are the common cause of global disability. It can be said that osteoarthritis often arises from over using the knee joints and also excessive weight (internal and external) acting on the knee joint. This is because excess weight put additional stress on the articulating part of the knee; which tends to be the weight bearing part of the joint. Most research has proven that weight loss in young people can reduce the risk of osteoarthritis later in their life.

Even recently, it is very unclear how excess weight directly causes osteoarthritis. But from this study, it is just known that excess weight increases the acting stress at the point of articulation thus hastening the total breakdown of the articulating surface which is the last stage of arthritis. And at these stages, only total joint replacement is the option available.

Above all, this mathematical modeling represent approximation of real life, and it aim was to increase the accuracy with which these load are known specifically to a given implant design and to determine the parameters of bones geometry, their structures and also understanding that their characters define the corresponding biomechanical model as it is view from it geometry.

6.2 Recommendation

This studies and other studies that pertain replacement of synovial joint most especially the knee joint should be that very serious because there is tendency of increase in the case of osteoarthritis because most people are now becoming more obese due to their diet, physical inactivity, overeating, frequency in eating, psychological factor among other.

For the manufacturing of prosthetic knee joints, the model is to be put into consideration so as to know the nature and amount of force that will be coming through the femoral bone to act on the tibia plateau so as to avoid the case of revision surgery from that particular angle of compressive force that act downward.

Daily improvement of knee prosthesis design will eventually leads to a prosthetics design that will outlive a young user without any case of revision surgery or prosthetic failure.

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