MODELLING AND ANALYSIS OF KNEE FLEXION MOVEMENT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF TECHNOLOGY

IN

COMPUTATIONAL DESIGN (CDN)

SUBMITTED BY

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AUGUST 2020

STUDENT'S DECLARATION

I, Richa Rai, Roll No(s). 2k18/CDN/06 student of M.Tech (Computational Design), hereby declare that the thesis entitled "**MODELLING AND ANALYSIS OF KNEE FLEXION MOVEMENT**" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological university, Delhi in partial fulfillment of the requirement for the award of the degree of Master Of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Dissertation entitled "**MODELLING AND ANLYSIS OF KNEE FLEXION MOVEMENT**" which is submitted by Richa Rai, Roll No. 2K18/CDN/06 Mechanical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree Of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Prof. Vikas Rastogi
Professor
(Project Mentor)

ACKNOWLEDGEMENT

Research is a higher concept. It brings to test our patience, vigour, and dedication. Every result arrived is a beginning for a higher achievement. My project is a small drop in an ocean. It needs the help of friends and guidance of experts in the field, to achieve something new.

I found my pen incompetent to express my thanks to my guide and **mentor Prof. Vikas Rastogi, Professor, DTU** under whose kind and worthy guidance and supervision, I had the opportunity to carry out this work. It was only due to his advice, thoughtful comments, constructive criticism, and continuous vigil over the progress of my work with a personal interest that it has taken this shape. They have been a great source of encouragement.

To get an opportunity to carry out the project work in the well-equipped, ever developing laboratories in our institution, I would like to pay my deep sense of thankfulness to **Prof. Vipin, HOD, Department of Mechanical Engineering, DTU**.

I am very much thankful to my parents for their moral support and encouragement, which was giving me the strength to chase my goal. Without their support and inspiration, I would not able to complete my degree.

I would especially like to acknowledge my gratitude to all my dear friends for their consistent support, valuable suggestions from time to time to make this project worthy.

I take this opportunity to express my gratitude to all those who have supported me in completing my fourth-semester project work as a part of my degree program.

RICHA RAI

M. Tech (Computational Design)

2K18/CDN/06

ABSTRACT

The model of three-dimensional model of knee joint is based on MRI data which is built in Mimics Software, which included the three parts of knee bone, Femur, tibia and Patella. And then analyzed.

Dynamic finite element (FE) model (ANSYS) of knee will be developed to simulate both the kinematics and the internal stresses during knee flexion movement. My study is only focused on macroscopic level.

The 3 dimensional model will be used to simulate knee gait system of a healthy volunteer. The flexion motion and dynamic contact characteristics of knee will be analyzed, and will be verified by comparing with the data from experiment. The results will show that the established dynamic Finite Element model of the knee are capable of predicting contact stresses during flexion.

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CHAPTER-1

INTRODUCTION

1.1 A BRIEF INTRODUCTION OF BIO-MECHANICS

Biomechanics is the study of the movement of living things, using mechanics (Hatze, 1974). Mechanics is a part of physics that deals with the motion and how forces create motion. Forces, which act on living things can create motion, be a healthy stimulus for growth and development, or overload tissues, causing injury.

Biomechanics provides conceptual and mathematical tools that are necessary for understanding how living things move and how kinesiology professionals might improve movement or make movement safer. Biomechanics is the study of how the systems and structures of biological organisms, from the smallest plants to the largest animals, react to various forces and external stimuli.

In humans, biomechanics often refers to the study of how the skeletal and musculature systems work under different conditions. In biomechanics more generally, scientists often try to apply physics and other mathematically based forms of analysis to discover the limits and capabilities of biological systems.

Since biomechanics is the study of human movement and interaction with the environment. This field has many applications in daily life and touches on many different sizes.

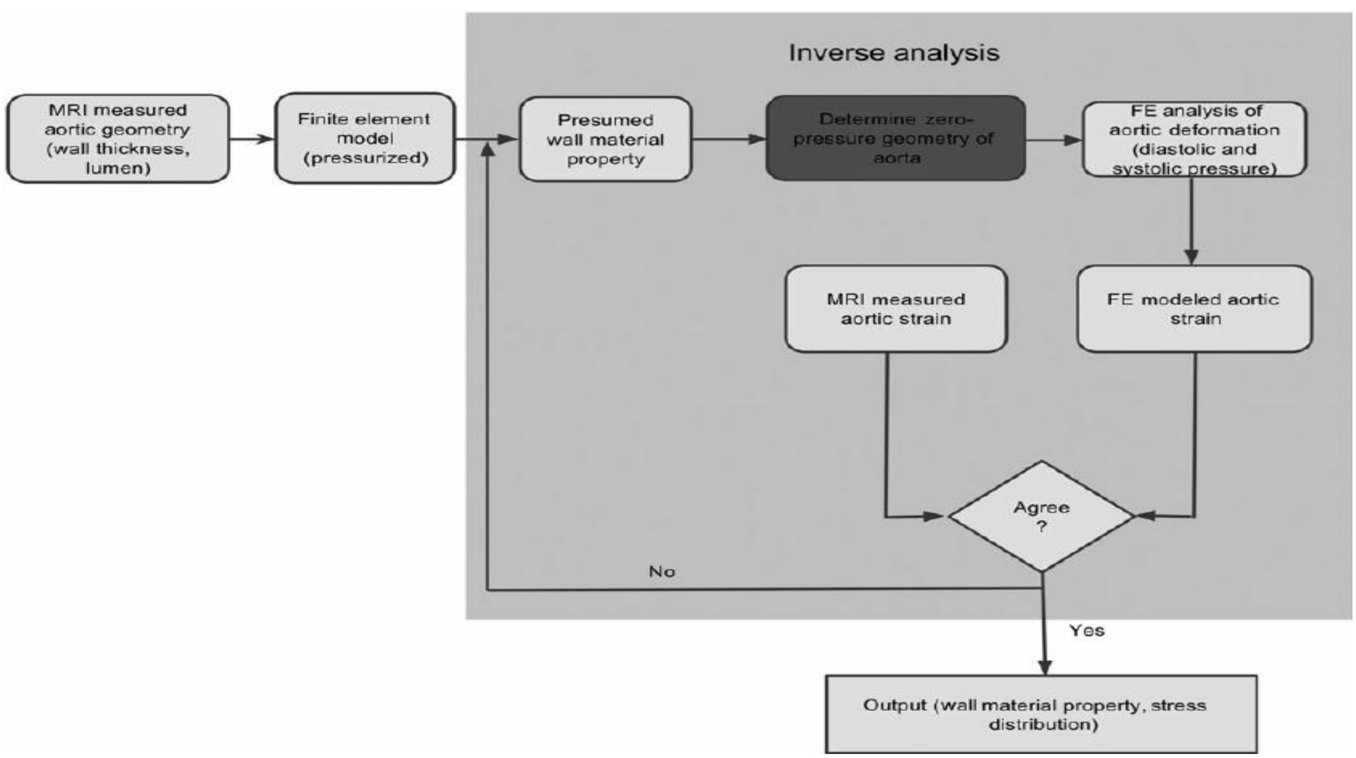


Fig 1.1 Importance of Bio- Mechanics

MECHANICS:

Mechanics is deal with the studies of the motion and the forces that cause the motion. Mechanics is divided into many areas, but the 3 main areas most relevant to biomechanics are:

1 Rigid-Body.
2 Deformable-Body, And
3 Fluids.

In rigid-body mechanics, the object is analyzed and assumed to be rigid, and the deformations in its shape so small they can be ignored.

The rigid-body assumption in studies save considerable mathematical and modeling work without great loss of accuracy.

DEFORMABLE-BODY MECHANICS

This studies how forces are distributed, and it can be focused at many levels, it may be on cellular to tissues to examine how forces stimulate growth or cause damage.

RIGID-BODY MECHANICS

It is divided into Dynamic and statics. Statics is based on the study of objects at rest or in uniform motion. Dynamics is based on the study of objects, which is being accelerated by the actions of forces.

DYNAMICS

Dynamics is divided into two branches:

1 Kinematics and
2 kinetics

KINEMATICS

Kinematics is describe the motion. When the objects is in motion are usually measured in linear like meter, when it is not in linear motion it is measured as angular.

KINETICS

Kinetics is deals with the causes of motion. Information of kinematics is more powerful in improving motion of human.

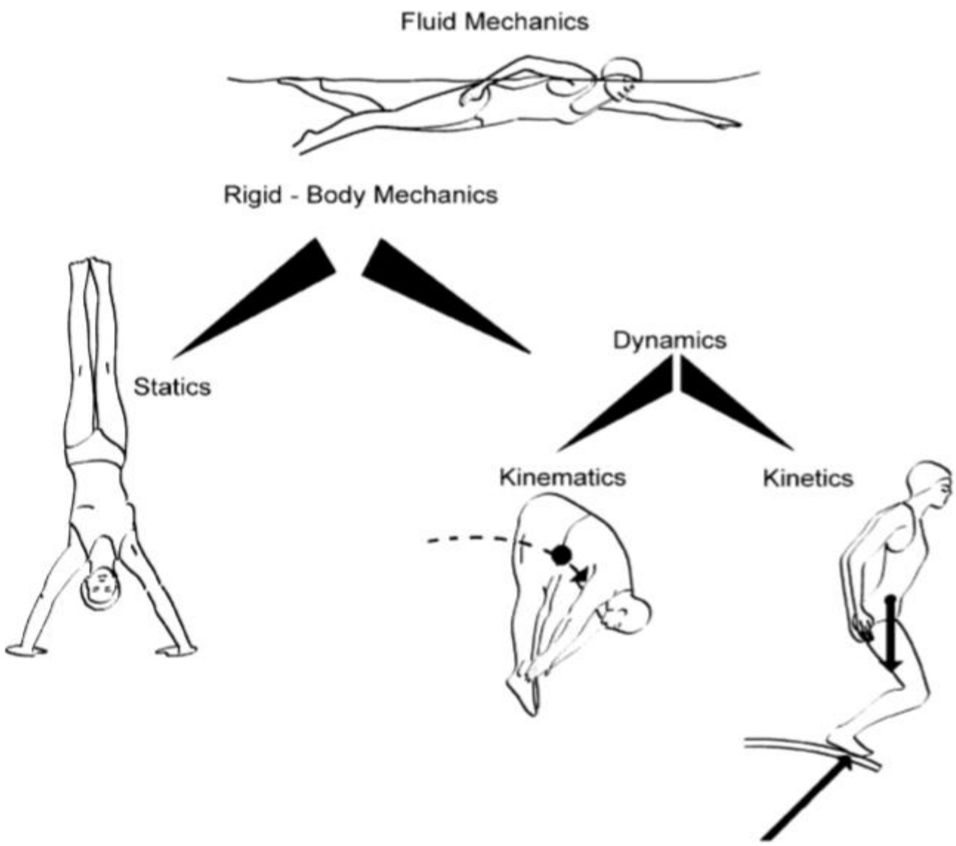


Fig 1.1.1 Introduction of mechanics

Basic Units:

Scalars

Scalar are variables that can be completely represented by a number and the units of measurement. The number and units of measurement (10 kg, 100 m) must be reported to completely identify a scalar quantity.

Vectors

Vector are complicated quantities, where unit, sizes, and direction must be specified.

QUALITATIVE AND QUANTITATIVE ANALYSIS

Analysis of both the quantitative and qualitative means identification of the factors that affect human movement performance, which is then interpreted using other higher levels of thinking (synthesis, evaluation) in applying the information to the movement of interest.

Biomechanics provides information for a variety of kinesiology professions to analyze human movement to improve effectiveness or decrease the risk of injury.

Quantitative Analysis

Quantitative analysis involves the measurement of biomechanical variables and usually requires a computer to do the voluminous numerical calculations performed. Even short movements will have thousands of samples of data to be collected, scaled, and numerically processed.

Qualitative analysis

Qualitative Analysis "systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance".

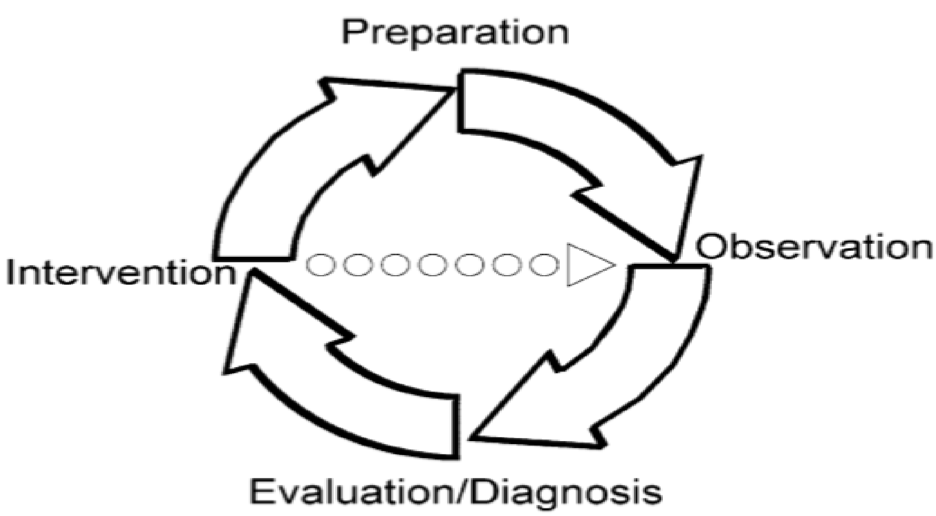


Fig 1.1.2 about analysis of biomechanics parts

1.2 A BASIC MECHANISM OF KNEE JOINT

Knee joint is the largest joint of human body, the function of knee joint is to allow movement of the leg and is critical to normal walking. Inside the knee a smooth articular cartilage that covers the joint surface, resting on the top of tibial cartilage is meniscus which improves the stability of joint and helps to distribute weight.

Anterior cruciate and the Posterior cruciate ligaments are important ligaments that control forward and back word motion of knee joint. The quadriceps tendons and the patellar tendons are thick fibrous tissues important to the extensor mechanism of the knee.

Ligaments are important to controlling excessive motion by limiting joint mobility especially side to side movement. Together these tendons and ligaments provide extension and flexion as well as medial and lateral rotation of knee joint.

The quadriceps muscles play a vital role in the stability of the knee and are anchored onto the top of the patella.

Knee is made of three bones, the femur, patella and tibia. Here we are taking right knee of human and looking straight at it.

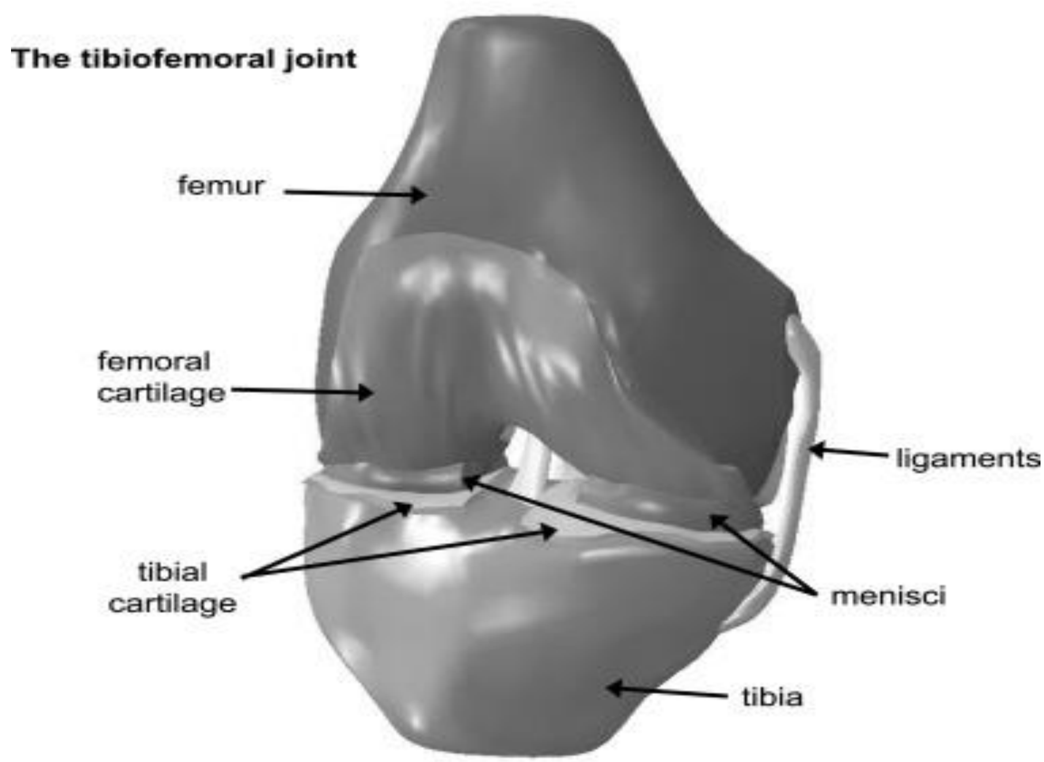


Fig 1.2 parts of knee joint

THE ANTERIOR VIEW

It has medial condyle in right side and lateral condyle in left side. Patella articulate with the femur and Patella is the biggest seamed bone of the body. The Fibula which does not make up the knee joint rather it articulate with the tibia, the shinbone which does make up the knee joint.

The knee joint is special because there between the joints are fibro cartilaginous structure called meniscus. The meniscus sits between the joint of femur and tibia. There is medial and lateral meniscus. These meniscus basically are shock absorber and helps to stabilized joint. It also has a role in distribution of the synovial fluid, the knee joint is further stabilized by many ligaments like, lateral, collateral ligaments in left side and medial collateral ligament in right side.

Here is in middle which joint the both the bones is quadriceps tendon which essentially attaches and over lies the patella bones and then forms the ligaments.

The patella bones has patella ligament(also known as patella tendon) which runs and attaches(join) to the tibial tuberosity which can inflamed and can undergo micro avulsion which is characteristics of Oshkosh late syndrome.
The patella ligament is actually the continuation of quadriceps tendons formed by the femoris muscles and the vastest muscles of the thigh.

BURSA

The bursa are fluid filled sacs that help to reduce friction. Knee has many bursa, suprapatellar bursa found above supra of the patella, the pre patellar bursa found on top of the patella below the tendons and skin. The infrapatellar bursa which is below the patella. Bursa can inflame because of irritation between the skin and the bone from overuse and friction (between the skin and patella leading inflammation of the bursa between the two)'

ANTERIOR VIEW FLEXION OF RIGHT KNEE

Here is patella on top because it's bent, here in the blue is medial and lateral meniscus and anteriorly is the transverse ligament joining the anterior parts of the lateral and medial meniscus, relevance of this is that it supposedly prevents the meniscus from moving forward essentially. Inside the knee joint we have important ligaments, these two have their named as to where they attach onto the tibia bone.

THE ANTERIOR CRUCIATE LIGAMENT, ACL

Ligament is a ligament which runs from the back of the femur and attaches to the front of the tibia front as an anterior. ACL prevents the tibia from sliding out in front of the femur.

ANATOMY OF KNEE JOINT

The knee joint is one of the largest and most complex joints in the body. It is constructed by 4 bones and an extensive network of ligaments and muscles. The knee is a joint formed, stabilized and given mobility by the articulation of bones, ligaments and tendons.

Knee joint made of three bones:

1. Femur is a thigh bone
2. Tibia is a shin bone
3. Patella is a Knee cap

Knee is complex joint with many different combination of parts:

1. Tendon
2. Ligaments
3. Bones
4. Muscles

Well-functioning healthy knee is essential for mobility and ability to participate in various activity. Knee is "Hinge joint" made of two bones Thigh bone and shin bone.

Two round knob at the end of Femur are called Femur condyles, these condyle rest at the top surface of Tibia and this Tibia surface is called "Tibia plateau". The thigh bone (Femur), the shin bone (Tibia) and the kneecap (Patella) articulate through tibiofemoral and Patellofemoral joints.
These three bones are covered in articular cartilage which is an extremely hard, smooth substance designed to decrease the friction forces.

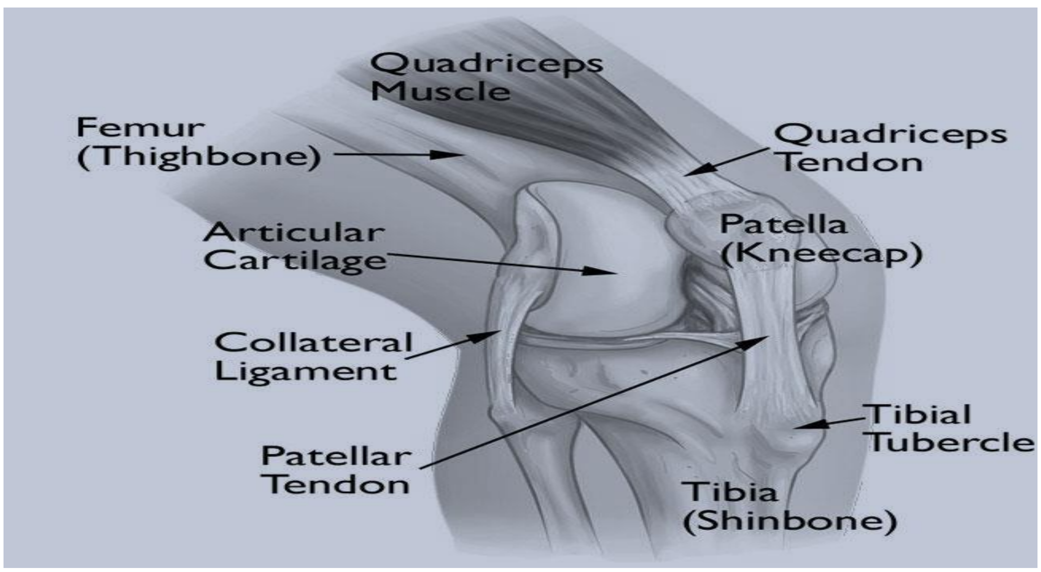


Fig 1.2.1 knee bones

FEMUR (THIGH BONE):

Femur, also called thighbone, upper bone of the leg. The head forms a socket and ball joint with the pelvic arc, being held in place by a ligament within the socket and by strong surrounding ligaments.
In humans the neck of the femur connects the shaft and head at a 125° angle, which is efficient for walking.

TIBIA (SHIN BONE):

The tibia is a large bone located in the lower front portion of the leg. The tibia has its second name "the shinbone", and Tibia is the second largest bone in the body. There are two bones in the shin area: the tibia and fibula. The fibula is smaller and thinner than the tibia.
These two bones connect the ankle to the knee and work together to stabilize the ankle and provide support to the muscles of the lower leg; however, the tibia carries a significant portion of the body weight.

PATELLA (KNEE CAP):

The patella or kneecap, is a flat, circular or triangular bone, which is connected with the femur and protects the anterior surface of the knee joint.

Fig 1.2.2 Patella or knee cap

CARTILAGE AND MENISCI:

Movement of the bones cause friction in the articulating surface, to reduce this friction between all articulating surfaces involving in movement, are covered with a quite shiny and slippery layer called Cartilage.
Articulating surface of femoral condyle and Tibia Plateaus cartilage and the back of the petal cartilage are covered with the Cartilage.
This provide smooth surface that facilitate easy movement and further reduce friction between articulating surface of the bones or “knee joints”.

MENISCI

Between the knee joints, femur and tibia, there are two ‘C’ shaped cartilaginous structure called menisci.
Menisci provide stability to the knee by spreading the weight of upper body across the whole surface of the tibia plateau.
Helps in load wearing by preventing weight from concentrating onto a small area, which could damage the articulate cartilage.
Also act as a cushion between the femur and tibia by absorbing the shock produced by activity such as walking, running, jumping and squatting etc.

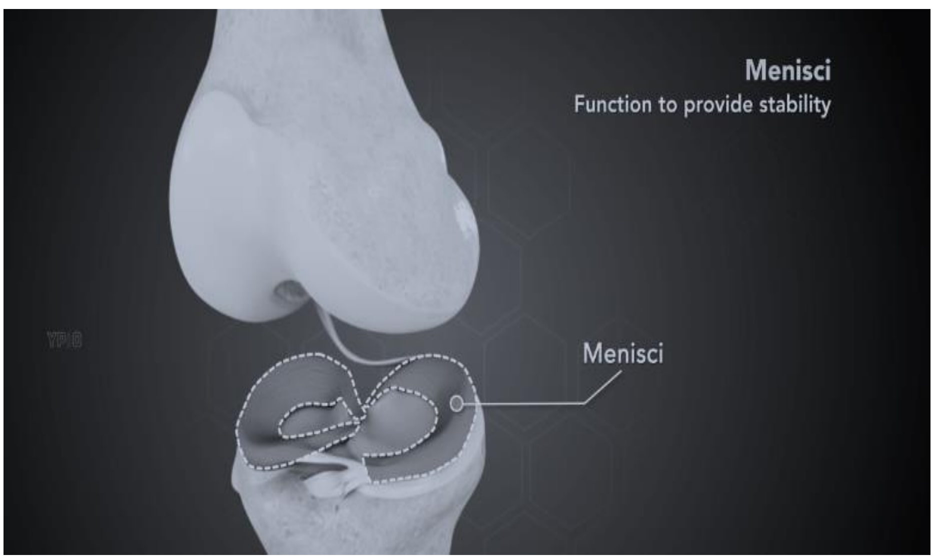


Fig 1.2.3 knee menisci

1.3 OVERVIEW OF KNEE JOINT

1 Tibiofemoral Joint
2 Patellofemoral Joint

Human leg consists of two joints:

1 First one is between tibia and Femur is known as Tibiofemoral Joint.
2 And second one is between the femurs and Patella is known as Patellofemoral Joint. It is the one of the largest joint in the human body. The knee is a known as modified hinge joint, this modified hinge joint permits flexion and extension as well as internal and external rotation**.**

TENDON:

A Tendon is a tough band of fibrous connective tissues which is made of Protein, that connect muscles to bone and is capable of withstanding in tension.

LIGAMENTS:

A ligament is the fibrous connective tissues that connects **bones to other bones**. It is also known as articular ligament, fibrous ligament, or true ligament.

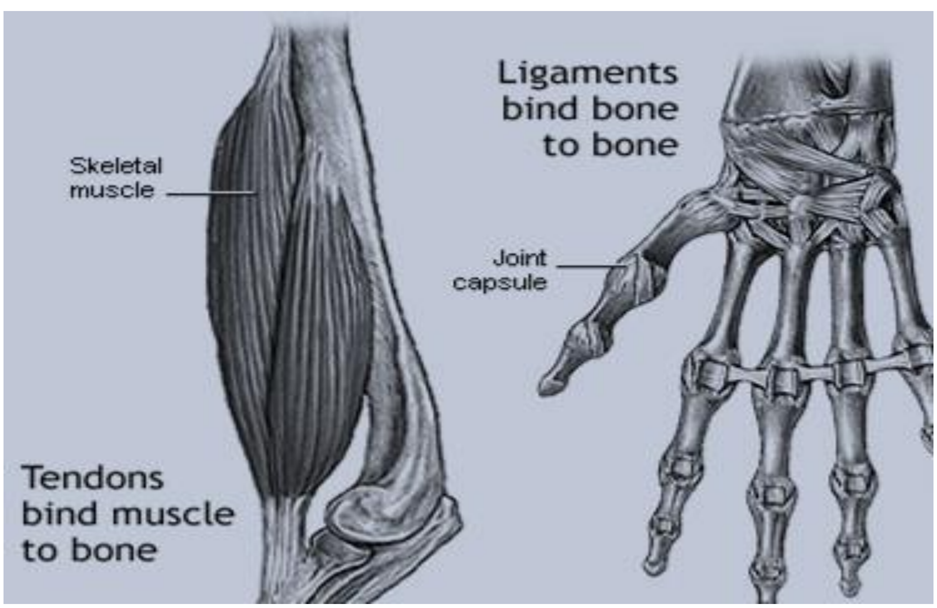


Fig 1.3 muscles of knee joint

TYPES OF LIGAMENTS

To stabilize the knee joint two important types of Ligaments is:
Collateral Ligaments.

1. Cruciate Ligaments
2. Collateral ligaments

Collateral ligament is used to prevent the knee from moving too far, during side to side motion.

1. Medial(inside)
2. Lateral(outside)

1 CRUCIATE LIGAMENTS:

Cruciate ligament is used to prevent or control back and forth motion inside the knee joint.

1. Posterior (back of the knee)
2. Anterior (Front of the knee)

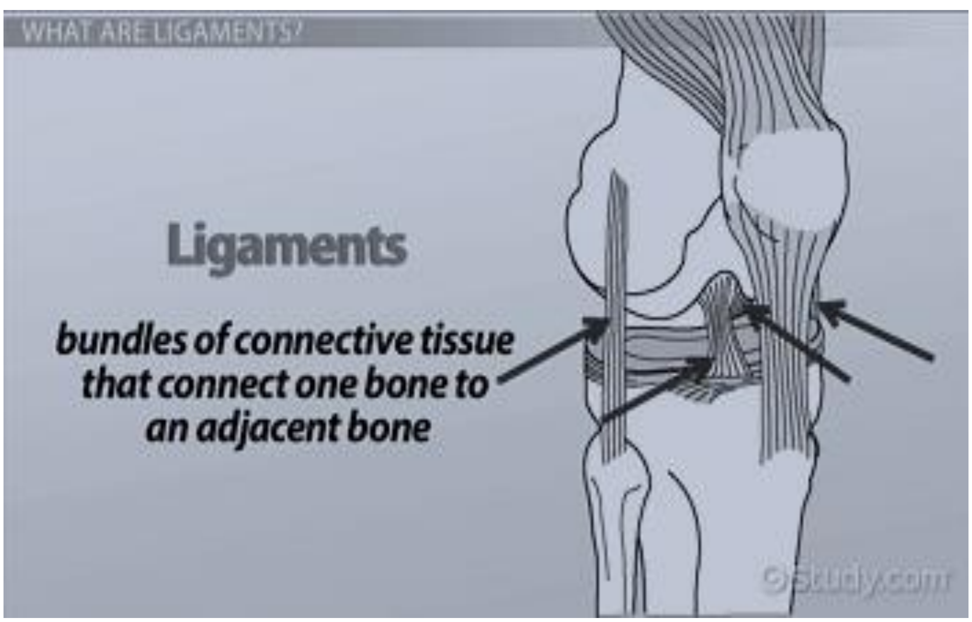


Fig 1.3.1 ligaments of knee joint

MUSCLES OF KNEE JOINT

The muscles of the knee includes the quadriceps and hamstrings. These muscles work in groups to flex, extend and stabilize the knee joint. These motions of the knee allow the body to perform such important movements as walking, running, kicking, and jumping.

1 QUADRICEPS:

Located at the front of thigh, when quadriceps of the muscles contract the knee strengthened.

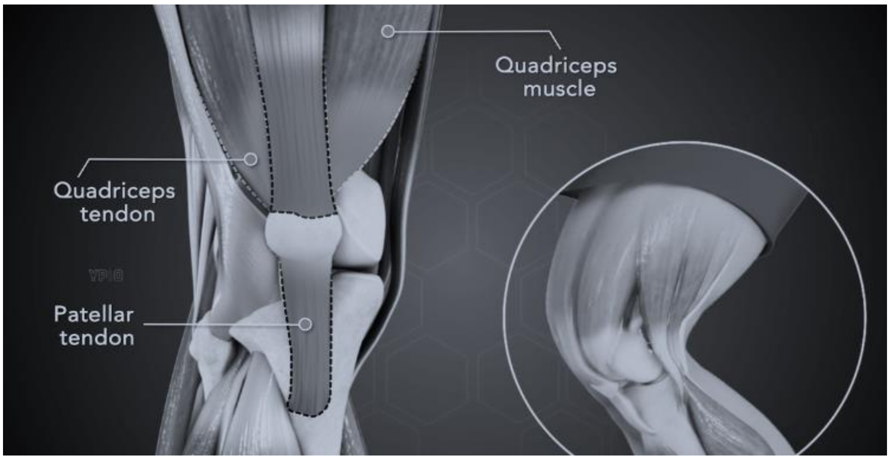


Fig 1.3.2 Quadriceps muscles of knee joint

2 HEMSTRINGS:

Located at back of thigh. Muscles contracted knee bends.

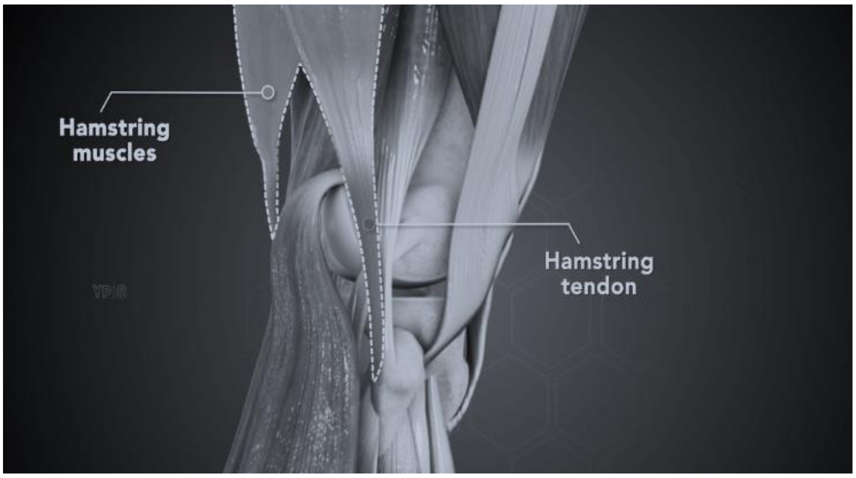


Fig 1.3.3 hamstring muscles of knee joint

1.4 INTRODUCTION OF FINITE ELEMENT ANALYSIS

FEA is finite element analysis based on the Finite element method,
This method we used to predict the behavior of Heat flow, the behavior of solids, heat conduction of fluid flow, Euler's equation, static

Analysis and many more. The finite Element Analysis tool is very popular and effective nowadays in Engineering and non-Engineering field. FEA provides results with precision, real-life scenarios with accuracy, versatility, and practicality. FEA working on finite element method. Which deals with practical problems.
FEA used to calculate or solve approx. the solution of real-world problems. It is based on the Mathematical model of the Differential equation. FEA perform different analysis and also it converts Mathematical differential equation into the set of linear equations. For Engineering problem Differential equation is playing a very important role because the language of physical laws is mathematics.
Differential equations connect everything like changes in displacement, the geometry of objects, physical properties, temperature and pressure, and so on.

LINEAR ANALYSIS

When forces are applied to a body, the body deforms which induce the stresses to make the state of equilibrium. The displacement, stress, strain and reaction forces are calculated by solving the equation

$$\boldsymbol{Kd} = \boldsymbol{F} \tag{2.1}$$

Where $\boldsymbol{K}$is the stiffness matrix, $\boldsymbol{d}$ is the displacement vector and $\boldsymbol{F}$ is the external force

The requirement for these equation to be applicable are that the deformation and rotation should be small(geometrically linear), the material behaviour sould be linearly elastic(obey hooke's law) and boundary constraint should be constant.

NON LINEAR ANALYSIS

Hooke's law valid till elastic region and we model irreversible material like plastic or damaged, these material is very difficult to model and analysis is complex.
Due to this behavior of material very necessary the knowledge of nonlinear analysis.
There are two types of non-linearity known as

1 Material Non Linearity

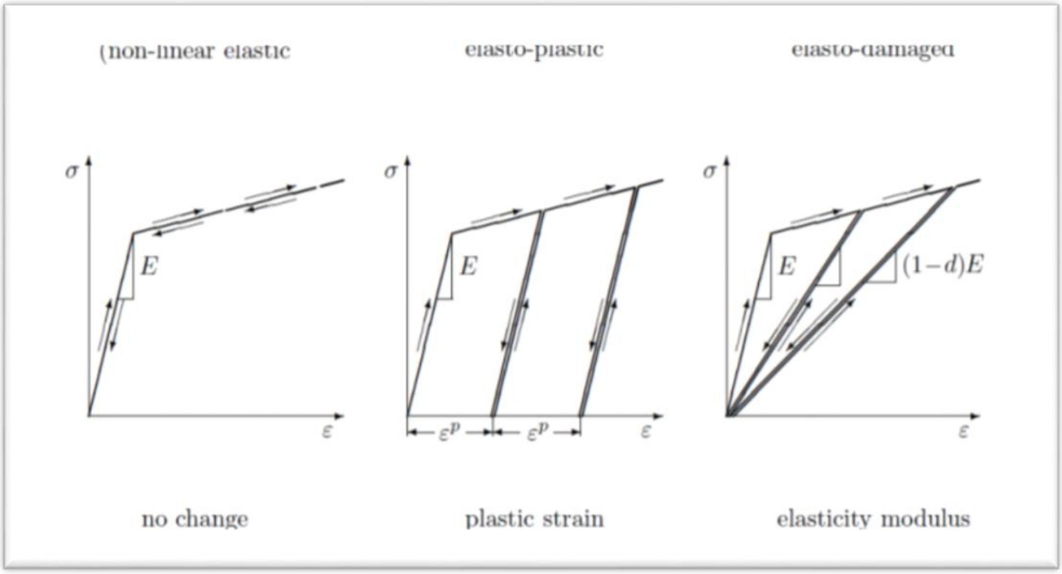
2 Geometrical Non Linearity

Material non linearity have three types

1 Elasto-damaged

2 Elasto-plastic

3 Nonlinear elastic



GEOMETRY NONLINEARITY

Geometry non linearity is a kinematic quantity, Lagrange strain has been described
The material motion at a point from reference to current position is describe with help of the displacement vector, the Green Lagrange strain tensor is given by

$$E = \frac{1}{2}[F^T.F - 1] = \nabla^{sym}u + \frac{1}{2}\nabla^T u.\nabla u = \frac{1}{2}[\nabla u + \nabla^T u + \nabla^T u . \nabla u]$$

STRESS AND STRAIN

Stress and strain important concept of solid FEA, Both are related to deformation in a solid body. External forces, pressure, and gravity, applied on a body will deform. Many factors affect the shape and magnitude of the solid body such as direction and magnitude of the force, the geometry of the solid body, and how the rigidity of the material. An example is the deformation of a spring.

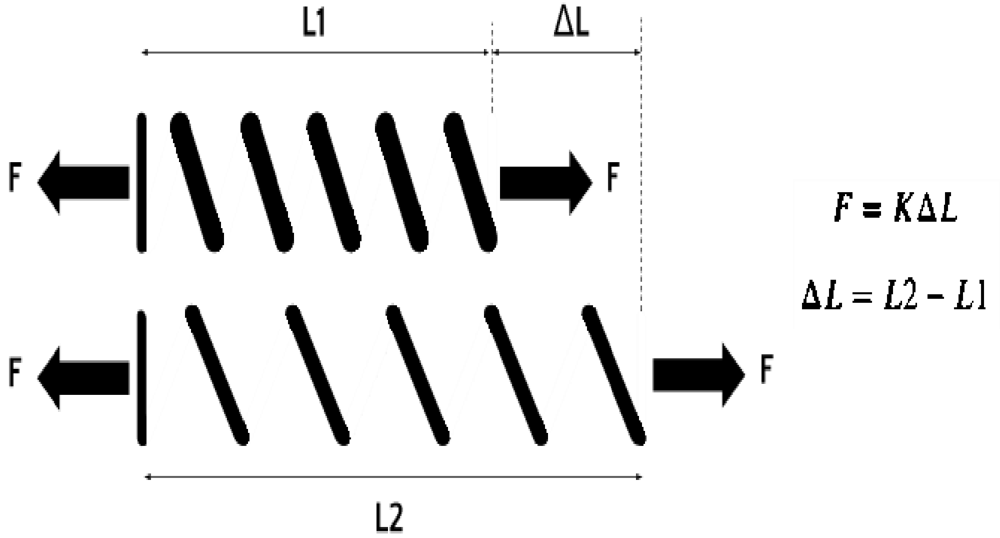


Fig 1.4 Stress and stain

STRESS

When we applied an external force on material or a solid body, then that force is balanced by some internal forces, and that internal force is known as stress.
Failure of the material occurs when stress of material crosses its maximum threshold value.

STRAIN

Strain is corresponding to stress, which provides hook's law under the elastic limit. Strain is ratio of Change in length to the original length is longitudinal stain.

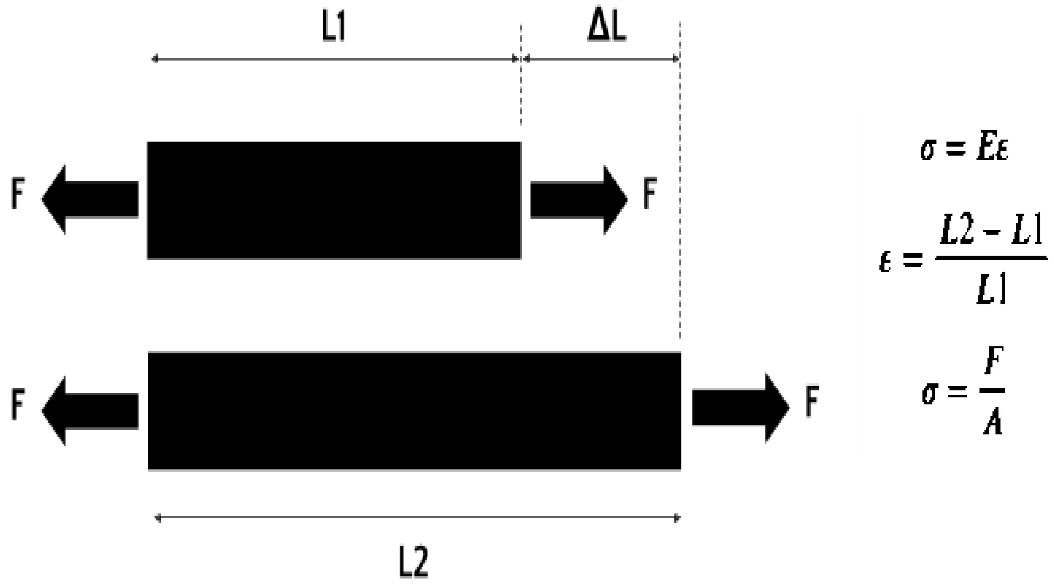


Fig 1.4.1 Uniaxial test diagram

Stress and deformation playing important role in FEM, and all the calculation based on FEA model mostly give stress and strain deformation.

For structural system there are many analysis.

3 Forced vibration

4 Buckling

5 Fracture propagation and mode of failure

6 Natural vibration.

KINEMATICS

Without causing forces the study of motion and deformation of material.

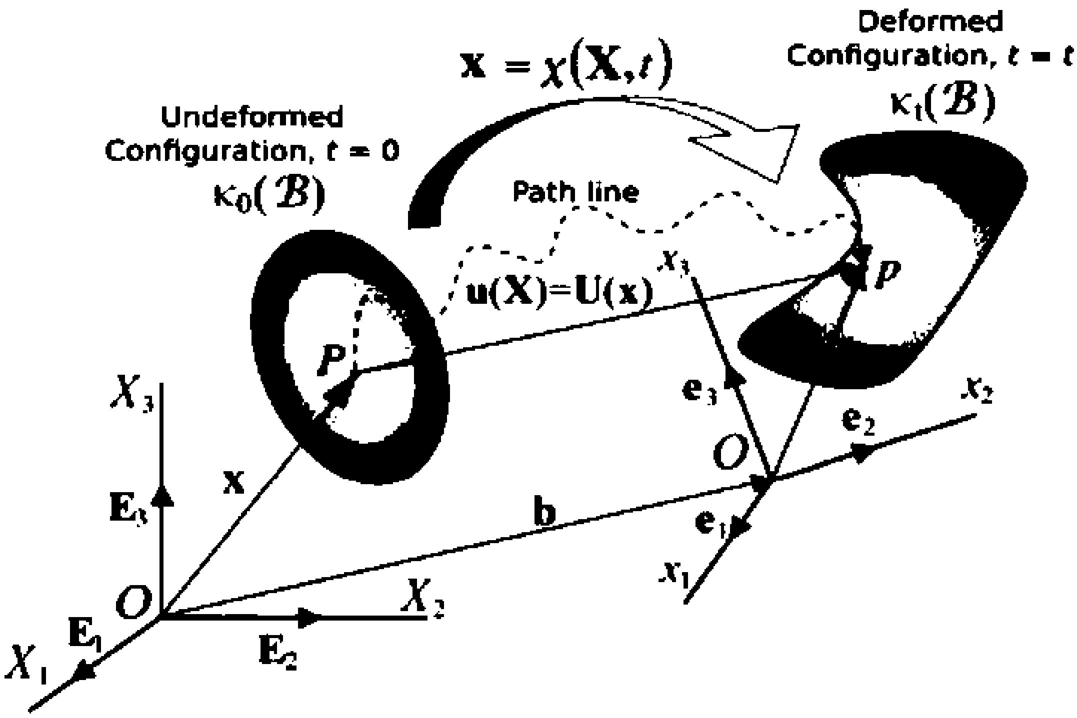


Fig 1.4.2 Kinematics of analysis

PRE AND POST-PROCESSING

Actually this is the most important part of the analysis, I has done in parts

1. Pre- processing
2. Post -processing

Physical problem

FEA through ANSYS software

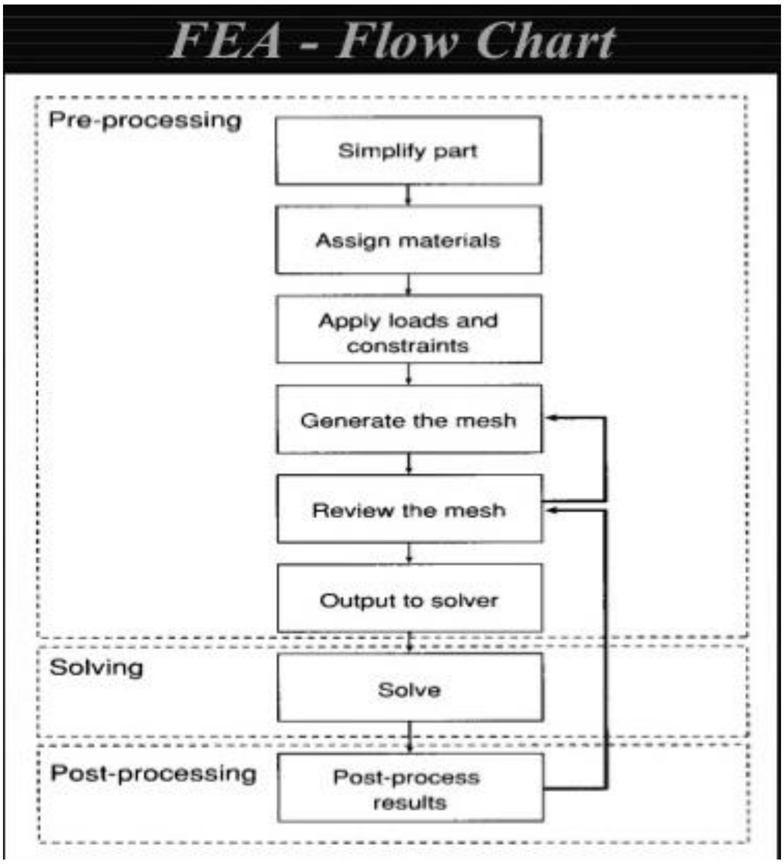
Preprocessor **FEM** - (Generates nodes, elements, boundary conditions, material properties, load and data file)

Solution **FEA** - (Generates element, matrices, compute nodal value, derivatives and store results)

Post processor **Analyze results** - (Display curves, counters, deformed shapes)

Physical problem

Fig 5.3 FEA analysis procedure



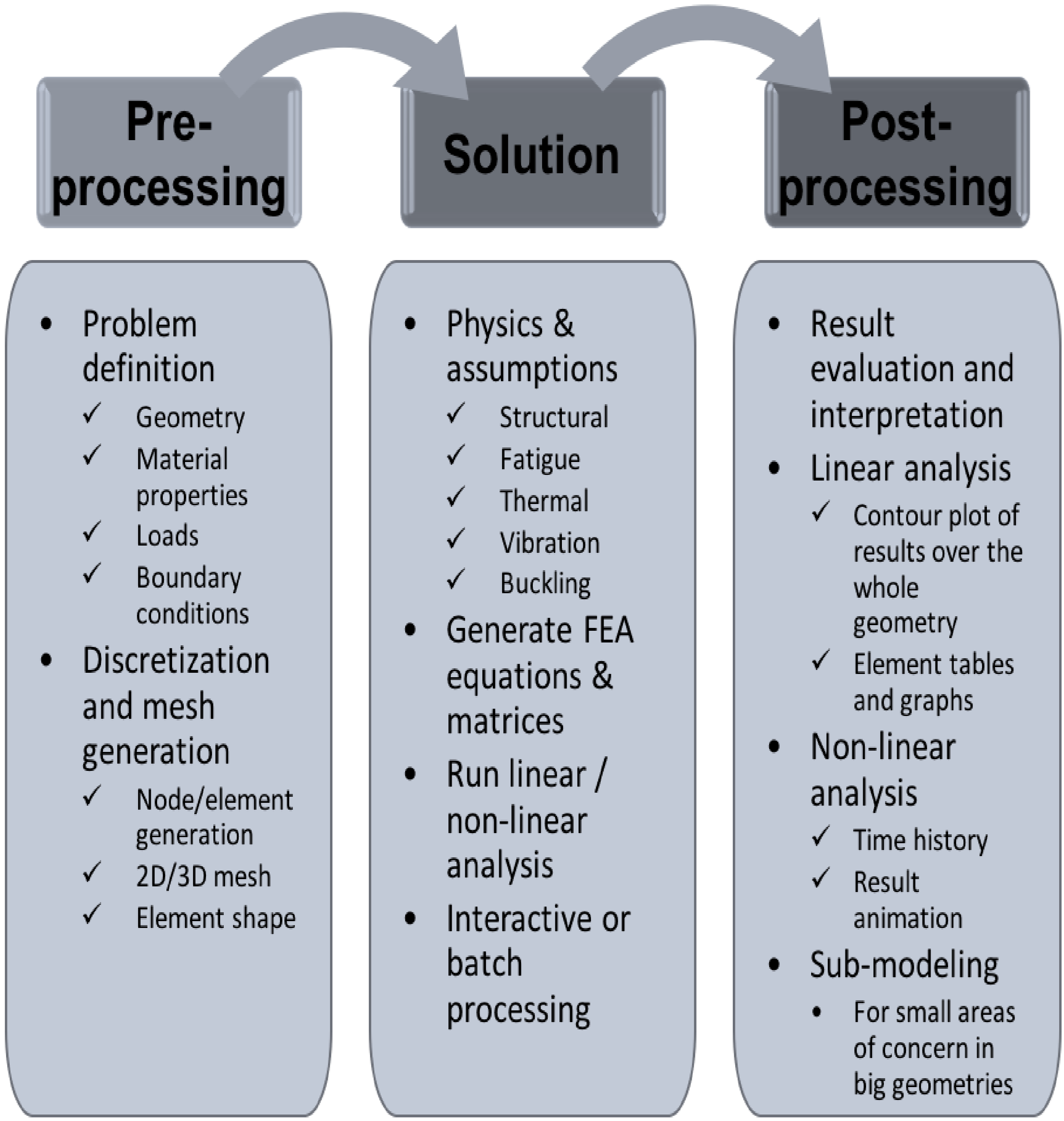


Fig 1.4.3 pre and post processing

1.3.1 BOUNDARY CONDITIONS, MATERIAL PROPERTIES, LOADS AND MESHING

When we have the 3D model or geometry, the most difficult task is to define boundary conditions.

Material Properties

We have to inform the software, in your 3D model, which parts of your model made of what material.
Material could be linear, elastic or plastic or something else. My focus is based on non-linear elastic material.

Non Linear Elastic Material

Knee joint behave like nonlinear material, so in human knee joint non-linear analysis is performed. Behavior Non- linearity in knee joint is because of contact surface.
Non-linear elastic material will not yield means after removing the material load away, the material is return to its original position.

Boundary Condition

It is a very important part of our Finite Element analysis. Boundary condition must be supportive to solve our model in order to calculate best suited result.

Load

Load is a basic requirement of our Finite Element Analysis, without proper loading condition we will not get accurate result. Must be aware of different type of loading condition.

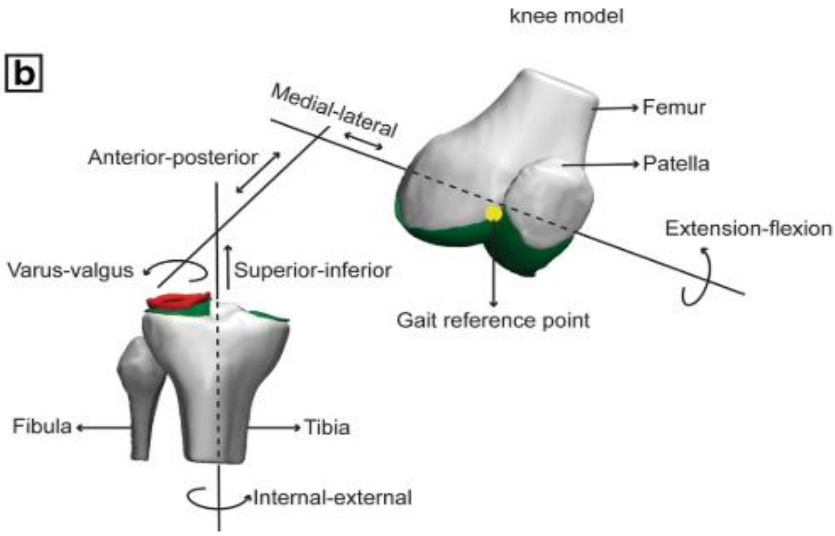
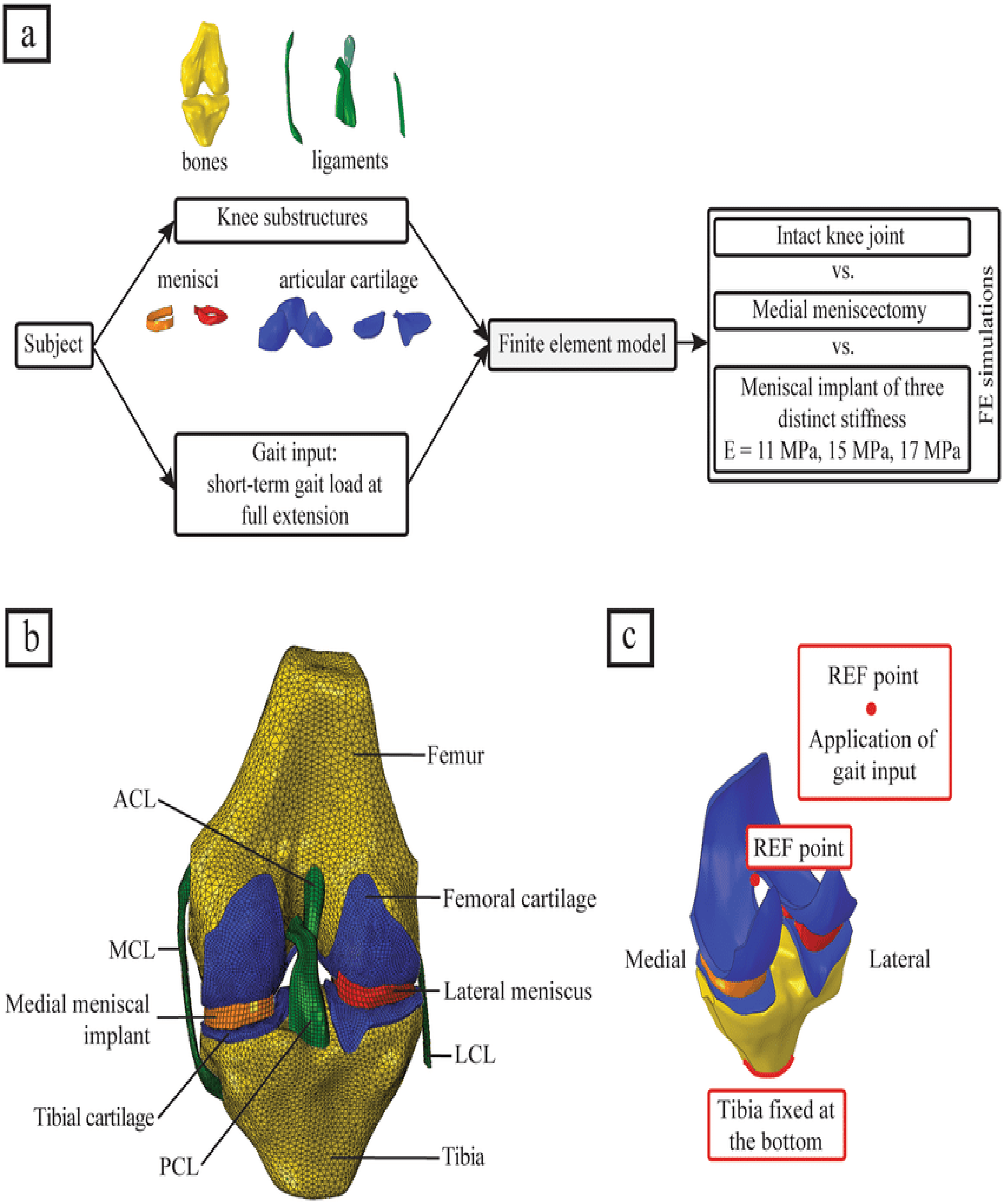


Fig 1.4.4 Introduction of mechanics


a
bones
ligaments
Knee substructures
menisci
articular cartilage
Subject
Gait input:
short-term gait load at
full extension
Finite element model
Intact knee joint
vs.
Medial meniscectomy
vs.
Meniscal implant of three
distinct stiffness
E = 11 MPa, 15 MPa, 17 MPa
FE simulations
b
Femur
ACL
Femoral cartilage
MCL
Lateral meniscus
Medial meniscal
implant
LCL
Tibial cartilage
PCL
Tibia
c
REF point
Application of
gait input
REF point
Medial
Lateral
Tibia fixed at
the bottom

MESHING

Without meshing we can’t get accurate result, there is basic difference in geometry and mesh.

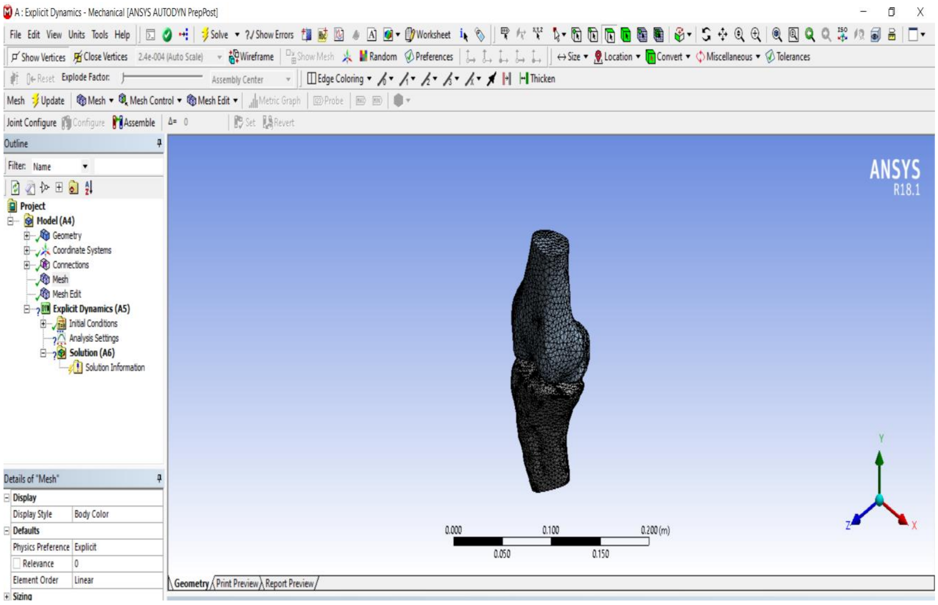


Fig 1.4.5 meshing

1 Element type

2 Actual meshing

3 Checking mesh size

The biggest problem is the size of mesh during analysis of 3D model. Bigger element mesh size will give bad results, and small size of mesh take long time for computation or for result. It is very important to choose accurate mesh size. We can see the example how mesh work in accuracy of result. So mesh convergent or refinement should be important for each problem no doubt it will take much time to solve the problem.

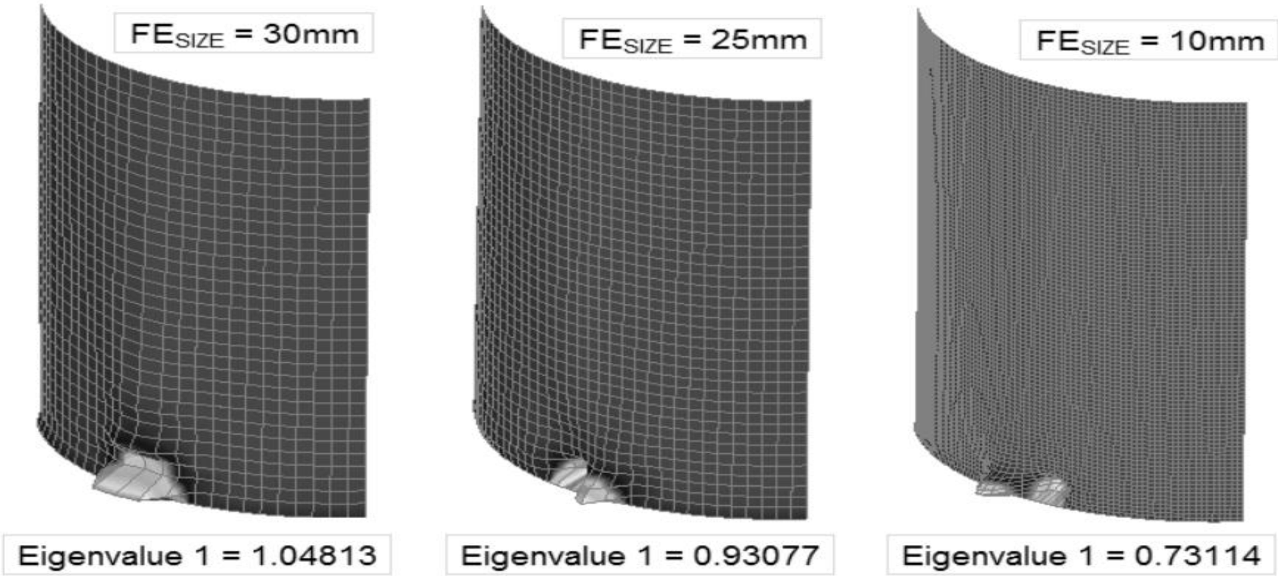


Fig 1.4.6 meshing size

VON MISES STRESS

To predict yielding of material or any geometry under dynamic and static loading conditions in simple uniaxial tensile and compressive tests is known as Von Mises stress. It satisfied the stress with equal distortion have equal Von Mises. Where k is yield stress of material in pure shear

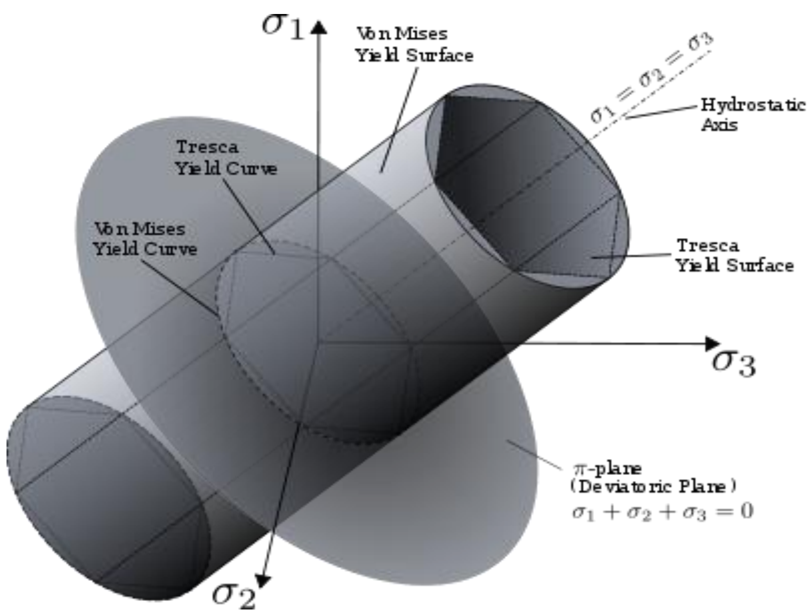


Fig 1.4.7 Von Mises different condition

Maximum and Minimum Principle Stress

Stress is follow transformation equation that’s why stress characterized as a Tensor. Principal stress is a normal stress at an inclined plane, where shear stress at that point is zero.

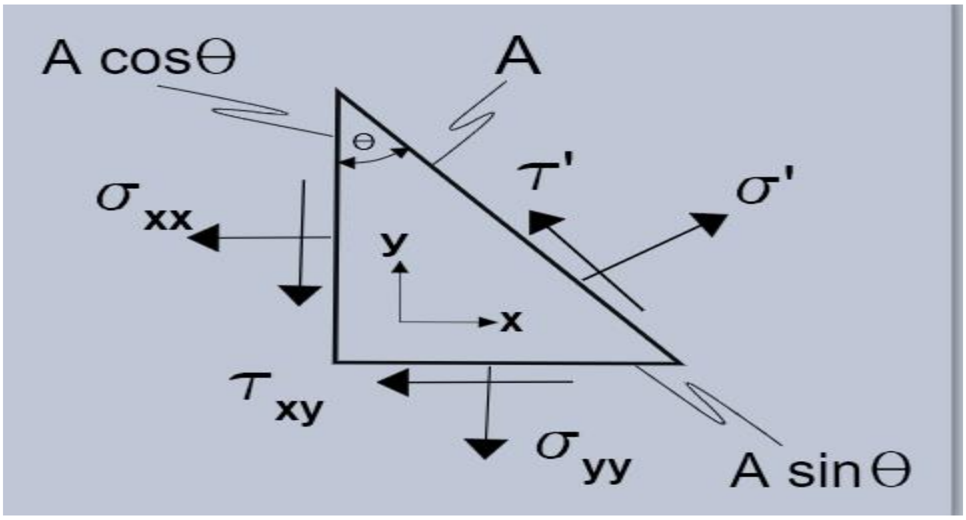


Fig 1.4.8 2D state of principal stress

Maximum stress and minimum stress is represented by Sigma.

$$\sigma_{max}, \sigma_{min} = \frac{\sigma_{xx} + \sigma_{yy}}{2} \pm \sqrt{\left(\frac{\sigma_{xx} - \sigma_{yy}}{2}\right)^2 + \tau_{xy}^2}$$

Maximum and Minimum Principal Strain

Principal strain is same as principal stress, Principal strain always one half of shear stress, it represented by gamma. $\gamma/2.$

$$\epsilon'_{xx} = \epsilon_{xx} \cos^2\theta + \epsilon_{yy} \sin^2\theta + 2\left(\frac{\gamma_{xy}}{2}\right) \sin\theta\cos\theta$$

$$\epsilon'_{yy} = \epsilon_{xx} \sin^2\theta + \epsilon_{yy} \cos^2\theta - 2\left(\frac{\gamma_{xy}}{2}\right) \sin\theta\cos\theta$$

$$\frac{\gamma'_{xy}}{2} = (\epsilon_{yy} - \epsilon_{xx}) \sin\theta\cos\theta + \left(\frac{\gamma_{xy}}{2}\right) (\cos^2\theta - \sin^2\theta)$$

Dynamic analysis is a part of Finite Element Analysis, Dynamic analysis is a very powerful tool to solve even a complex engineering problems. This analysis is also used to find out Potential noise, vibration and transient problems.

Explicit dynamic analysis is more accurate and efficient than implicit analysis, This Explicit analysis computation software is capable of solving large deformation, complex structural contact force, fracture and complete material failure it also include highly non-linear quasi static simulation .

In the Explicit analysis, the time integration method is used.

When geometry meshed properly this method will give accurate and current time explicit information. The next step is to define the boundary condition.

Once initial condition is defined, explicit dynamic solution depend on time steps.

1 Initial time

2 Minimum time

3 Maximum time

4 Time step safety

1.5 MATERIAL MIMICS SOFTWARE

Most important thing is how to import CT scan or MRI report images (DICOM format) to mimic software.

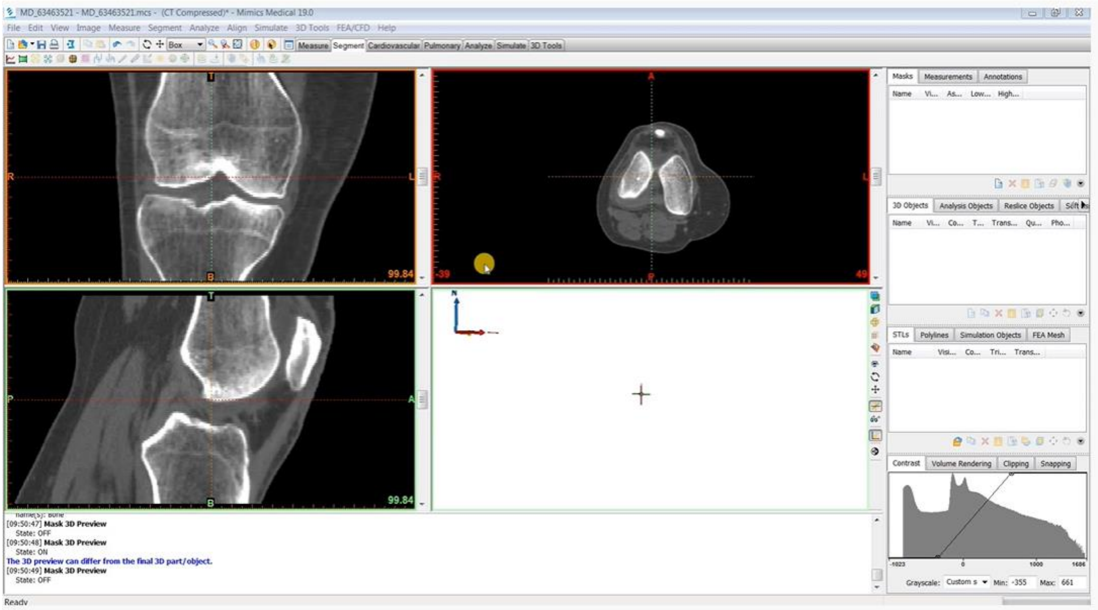


Fig 1.5 Basic view of mimic software

1. Go to file, choose new project wizard and import my raw DICOM images or file of knee then hit next.

2. Now we can see preview of our DICOM images, and all the in available.
3. Select the study you want to import.

4. Now it converted in mimics' project file, which will contain all our images file.
5. Now we can change the orientation of our images.

6. Now we will get 3 planner view of my knee joint. Top left is coronal plane, top right is axial plane, bottom left is sagittal plane and in bottom right is 3D window in which any 3D model can be create.

7. Right hand side of the software is project manager, which we have different tabs like segmentation etc.

8. Right hand side bottom right we have contrast tab, which we can used to adjust the windowing of our images, by dragging point around.

9. HOLD AND RIGHT CLICK drag mouse left to right can change the brightness of your images, Drag mouse up and down to change contrast your window.

1.5.1 SEGMENTATION AND THRESHOLDING

SEGMENTATION

An MRI or CT scan Image is imported in MIMICS Software, This software converts the two-dimensional image into the three-dimensional solid geometry. Segmentation is begun by cropping and providing right or required image in three view names is sagittal, axial, and coronal.

Mimics software reduces unwanted segmenting and fixed the wanted or required geometry. Profile line is in axial view in between two extremities of bones femur and tibia.

THRESHOLDING

Threshold operation is used to create mask. This mask connects all the region in same thresholds area. The mask which create automatically is green mask it shows after completing the threshold in cropping region. We use multi slicer editing between femur and tibia to create growing operation.

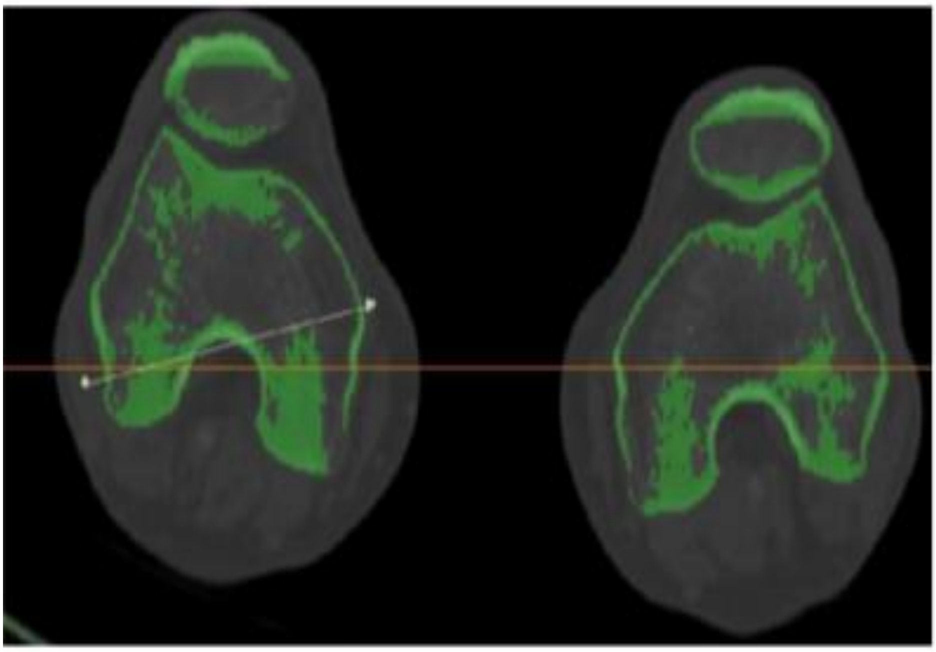


Fig 1.5.1 automatically generated green mask

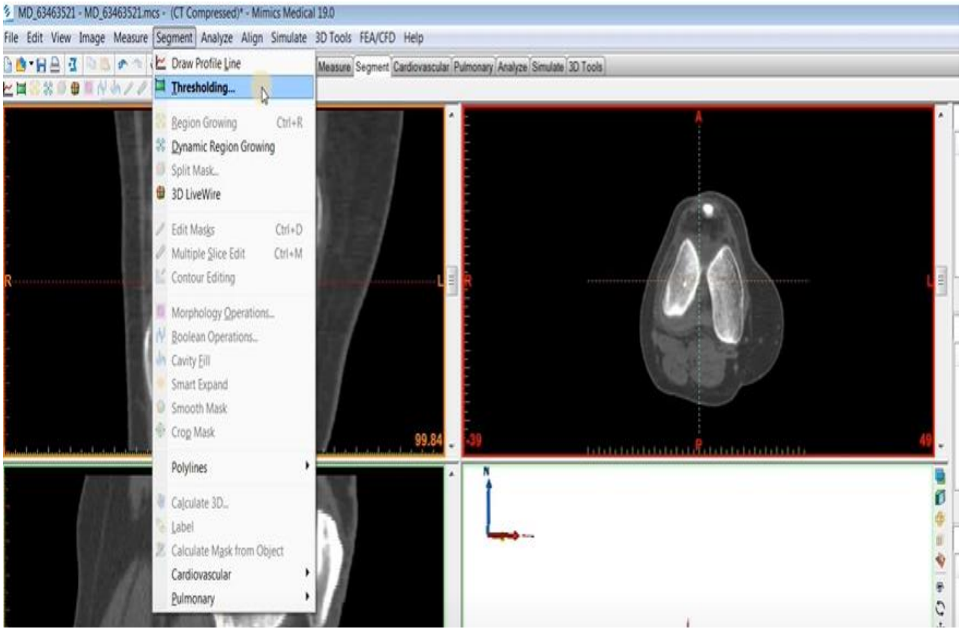


Fig 1.5.2 Thresholding

Most commonly used tool to create initial segmentation object. Go to the segment menu

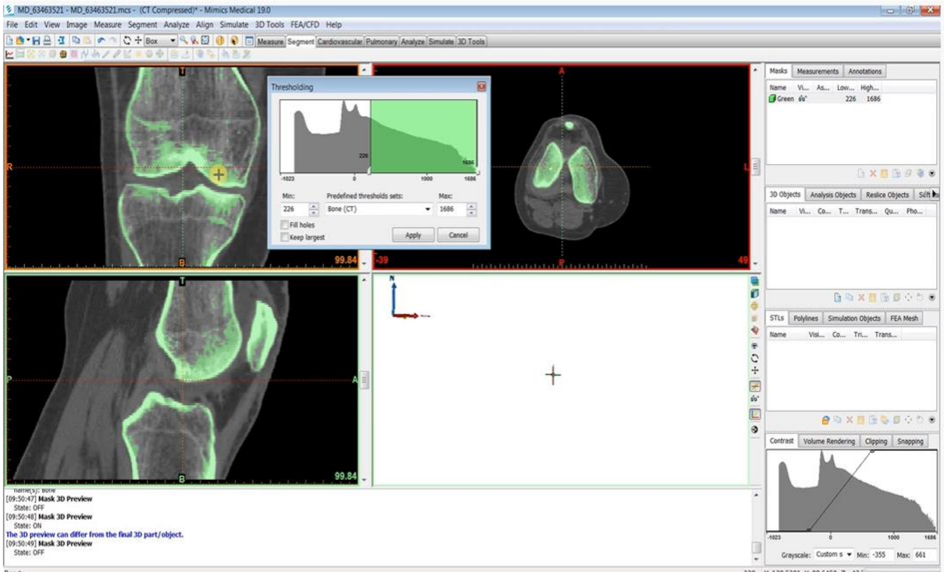


Fig 1.5.3 How to use Thresholding

1 So “THRESHOLDING” is the process of choosing the range and intensity values that used in any of the pixels that will fall within a range get highlighted or selected and put into our segmentation.

2 Number of pixel on Y axis and value of image are along the x axis.
We can choose or change our range by dragging the sliders or mouse left and right, and one is minimum value range and one is maximum value range.

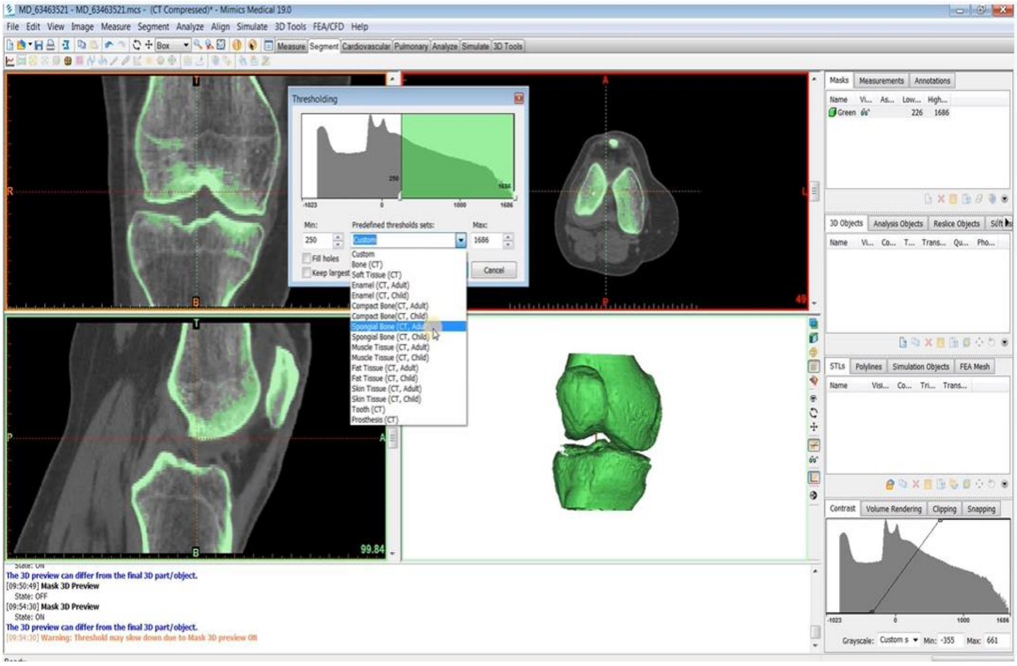


Fig 1.5.4 3D model of knee

So we can see as we drag the mouse the pixel will update in real time as well as my 3d view. It has some predefined sets of CT scan.

1.6 RESEARCH MOTIVATION

Bio-mechanics is the Part of mechanical engineering and principles of living things. It deals with organisms at a different level.

A combination of engineering fields deals with different levels of complexity, which is not possible by only the biomedical field, like analyzing the forces before actual practice is the basic need of engineering in the medical field.

The bone modeling cycle at bone mechanics is very challenging for everyone who's belonging to this field in mechanics and biomechanics, continuously changing structure and microstructures is provided basic changes in the bone mechanical properties. Small strains behavior in tissue, the bone scan shows large changing shape, this changing shape because of applying external forces remodeling.

Everything there makes bone a very good living tissue model of the prototype for the applications of the methods of Finite Element Analysis or in continuum mechanics. This modeling process is open systems mechanics to deals with the biomechanics system. This may be responsible for bone growth and analysis across the scales.

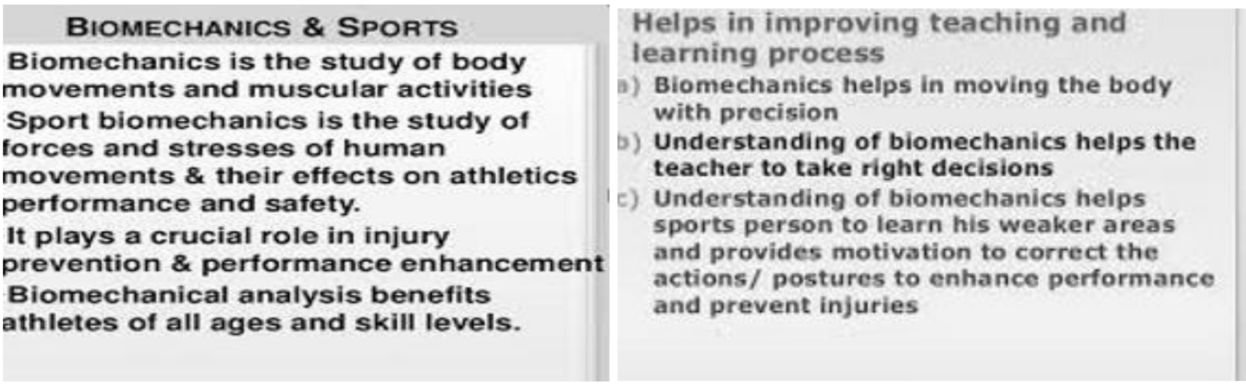


Fig 1.6 Motivation toward biomechanics

1.7 ORGANIZATION OF THESIS

The chapters of the thesis are arranged in the following manner.

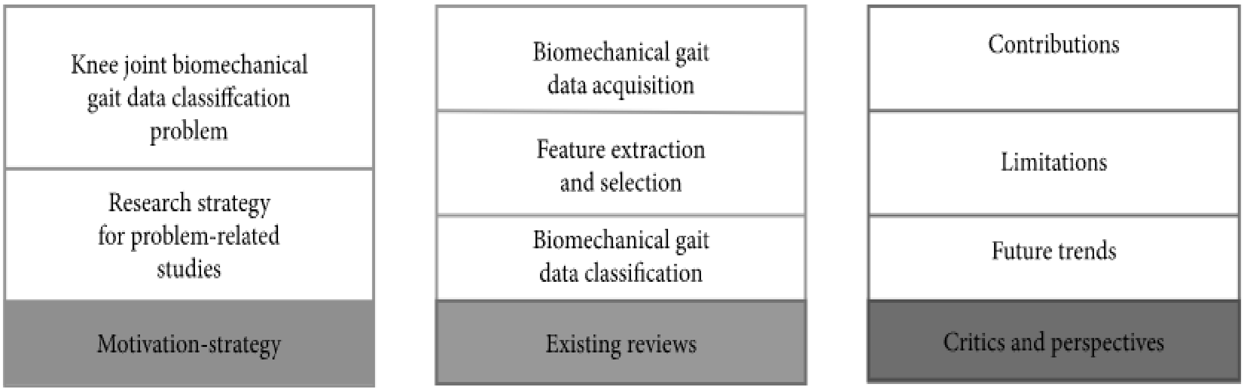
Chapter 1 discusses about the basics of knee joint, modelling and finite element.

Chapter 2 discussion of literature review.

Chapter 3 presents the generation of Solid model using mimics software.

Chapter 4 presents analysis and result.

Chapter 5 deals with results and discussion and concludes along with some scope for future work.



CHAPER-2

LITERATURE REVIEW:

S.N.	TITLE	RESEARCH WORK	RESULT	REFECENCE
1.	Knee joint forces and prediction, measurement, and significance.	Number of studies have been performed to estimate forces around the knee during various activities.	The various methods to alter knee force distribution, such as gait modification, walking aids, and custom treadmills are analyzed	**[11]**
2.	Functional Tissue Engineering and the Role of Biomechanical Signaling in Articular Cartilage Repair**.**	Articular cartilage is the thin layer of deformable. The primary functions of this tissue are to support and distribute forces generated during joint loading and to provide a lubricating surface.	Investigate the role of physical stimuli in regulating cartilage and chondrocyte activity, ranging from in vivo studies to experiments at the cell and molecular level	**[12]**
3.	Forces and Moments on the Knee During Kneeling and Squatting.	Knee angles, net force and momentum applied to the right tibia.	Significant differences were found between squatting and kneeling postures as well as between the high-flexion and lower-flexion	**[8]**

4.	Kinetics of joint While Squatting as well as moving With and Without an External Load	Single-group repeated measures design	In this conditions, human knee, Reaction forces and Patellofemoral joint reaction forces, stresses increased with greater knee flexion angles.	**[13]**

A large number of studies have attempted to find out forces on the knee during various activities. Most of the approaches have been used to compare or relate external forces and knee kinematics to the joint and contact forces. The most popular is forward, inverse dynamics, and static load analyses. Knee forces have been measured, which shows the validation of computational analysis. This Result summarizes all the published research papers that studied knee forces for various movements.

The importance of different methods is to define knee force analysis at different movements. The importance of different methods is to define knee force analysis at different movements, like gait modification, walking, and custom treadmills are analyzed. Current research gaps in our study are to discover, identify and directions are outline for our future research in this field.

Practically and theoretically measured forces much needed for our experimental and estimated model to compare. Knowledge of forces in the knee joint provides quantitative data to make informed decisions regarding the prevention and treatment of knee injury.

Knowledge of Knee forces will also be used in computer models that predict future outcomes, that can't be measured directly, the example is stress distributions, ligament, and muscle forces, wear, damage, and remodeling of studies have attempted to estimate forces.

CHAPTER-3

3.1 MODELLING OF KNEE JOINT

The ligaments and menisci provide static stability and the muscles and tendons dynamic stability.
The main movement of the knee is flexion-extension. For that matter, the knee act as a hinge joint, whereby the articular surfaces of the femur roll and glide over the tibial surface.
During flexion and extension, tibia and patella act as one structure with the femur. The quadriceps muscle group is made up of four different individual muscles. They join together forming one single tendon which inserts into the anterior tibial.
Embedded in the tendon is the patella, a triangular bone and its function is to increase the efficiency of the quadriceps contractions.
The contraction of the quadriceps pulls the patella upwards and extends the knee. Range of motion and quadriceps extension is zero degree.
The hamstring muscle group consists of biceps femoris. They are situated at the back of the thigh and their function is flexing or bending the knee as well as providing stability on either side of the joint line. Range of hamstring flexion is 140 degree.
Secondary movement is the internal-external rotation of the tibia concerning the femur, but it is possible only when the knee is flexed.

Patellofemoral joint stress:

1. This stress is defined as Patellofemoral joint reaction force, which is divided by the articular surfaces of the patella and femur and the area of contact.
2. The joint reaction of Patellofemoral, a patellar compression against the femur is measured, which is influenced by the angle of knee and the quadriceps force.
3. The joint stress Patellofemoral may remain constant from 0° to 60° and increase from 60° to 90°.
4. Studies of this joint have defined that during squatting, the Patellofemoral joint reaction force is minimal but, when the knee is extended but this extension increases steadily like the knee is flexed.
5. An external resistance would be added, so that, increase the joint reaction stresses and force throughout the squatting range.
6. Joint stress is defined as the Joint reaction force divided by the area of contact and the surfaces of the patella and femur.
7. The Patellofemoral joint reaction force, patellar compression is measured against the femur, which is influenced by the knee angle as well as the quadriceps force.
8. Biomechanical studies about the forces and joint reaction of Patellofemoral joint have demonstrated that during squatting. The Patellofemoral joint reaction force is minimal as compare to other, when the knee is extended but increases steadily as the knee is progressively flexed.

FEMUR BONE:

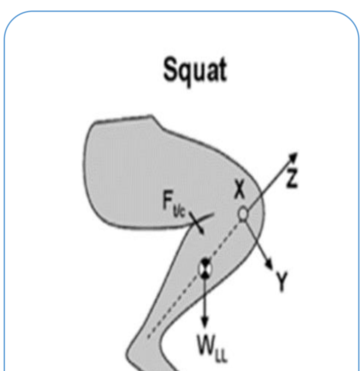
A femur bone is also known as thigh bone. The femur bone is the longest, heaviest, and strongest bone in the human body. The length of this bone is almost 26% of the height of the person. Requires the maximum amount of forces to break the bone.
A fracture occurs in femur bone only when the bone is affected with great force due to bending and twisting.
The Femoral neck is the region that connects the shaft of the femur bone to its round head that fits into a hip joint. The femoral neck is the region that is weak due to its small cross-sectional area and also due to the presence of Bone.

TIBIA LOADING:

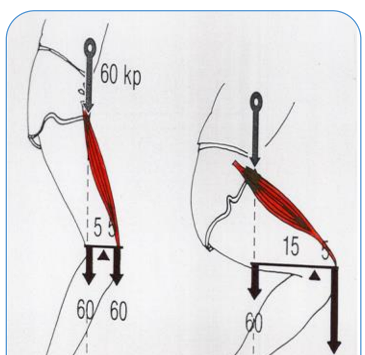
Different loading pattern created by squatting. The forces acting in the medial, posterior, and best directions of the tibia, Tibia consist of significant internal tibial rotation, which may be the main cause of the increase in the moment. These moments increase loading to the medial part of knee. During high flexion tibia femoral contact occurs at the back part of femur and tibia with maximum loading.

CARTILAGE AND MENISCI:

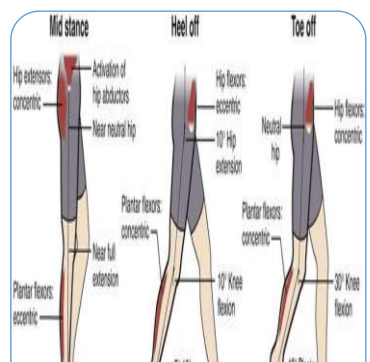
Cartilage and Meniscus are designed for high compressive loads in the central portion.



reaction force



knee reaction



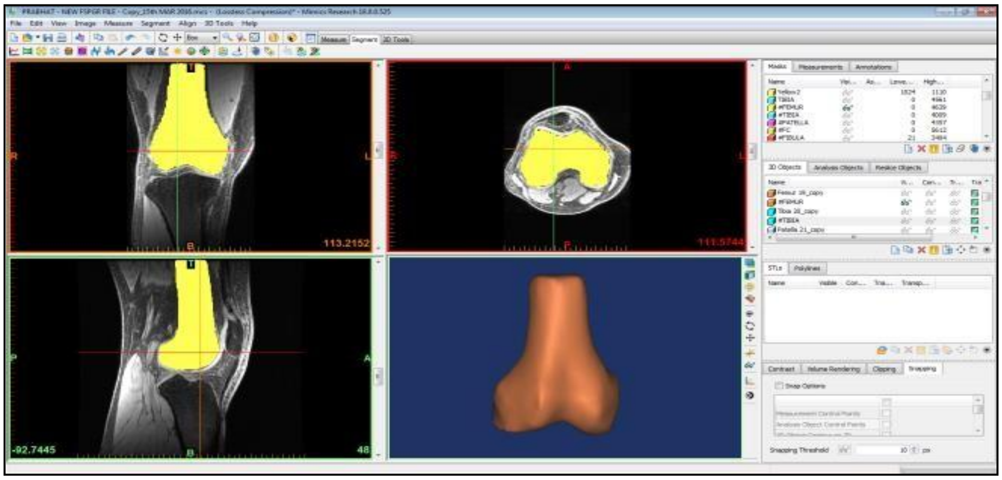
Human gait cycle

Fig 3.1 **Position of knee movement**

3.2 ANSYS SUPPORTING KNEE MODEL

Knee parts is reconstructed from the MRI scans using Mimics Research. The contour segmentation process in Mimics for the femur. Shows complete assembly of the knee joint. The 3D model of knee joint mesh generated by Mimics, which contain a large number of triangles.

Model Implant introduced to the specific material property exported to ANSYS in .IGES format.



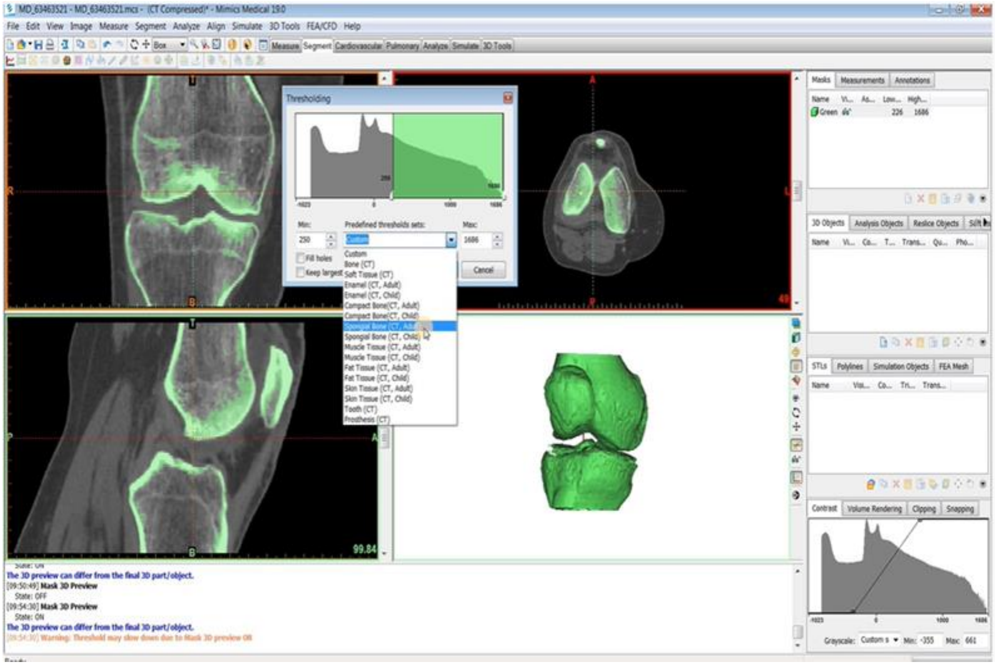


Fig 3.4 shows different view of knee

3.3 METHODOLOGY

To construct a knee model for the analysis of stresses on knee joint through MRI scan. The MRI images divided into many parts in which, three Images is taken by software,
Now a days we have several method to build 3d model of knee because of highly precise software including MIMICS, X ray image to construct 3d model, laser scan technique, Image processing, slicer reverse engineering and rapid prototype.
We are focused only on MIMICS software so some basic information about mimics software.
Mimics software
Mimics is a Materialize interactive medical image control system or software which used to build 3d images of complex shapes and it is also used in 3d printing. For construction of 3d image of knee we need MRI and CT scan of knee of a healthy human. And by importing that images in mimics software using thresholding and segmentation we can easily develop 3d model model of knee. After constructing the knee model we have to find out stresses on knee joint, so we use Ansys software to analyze the 3D model. Very difficult to analysis of soft tissues so, to avoid kinematic analysis of knee, all the component of knee has been taken rigid.

In many research paper authors have described about Finite element model of knee which includes bones and soft tissues of knee like tendon, patella, menisci and bones. Ligament is hyper elastic and isotropic, Bones are taken as rigid body but cartilage is taken as linearly elastic, homogeneous and isotropic. The model which I have explained was taken and validated by using experimental and software results.

CHAPTER 4.

DYNAMIC ANALYSIS OF KNEE JOINT:

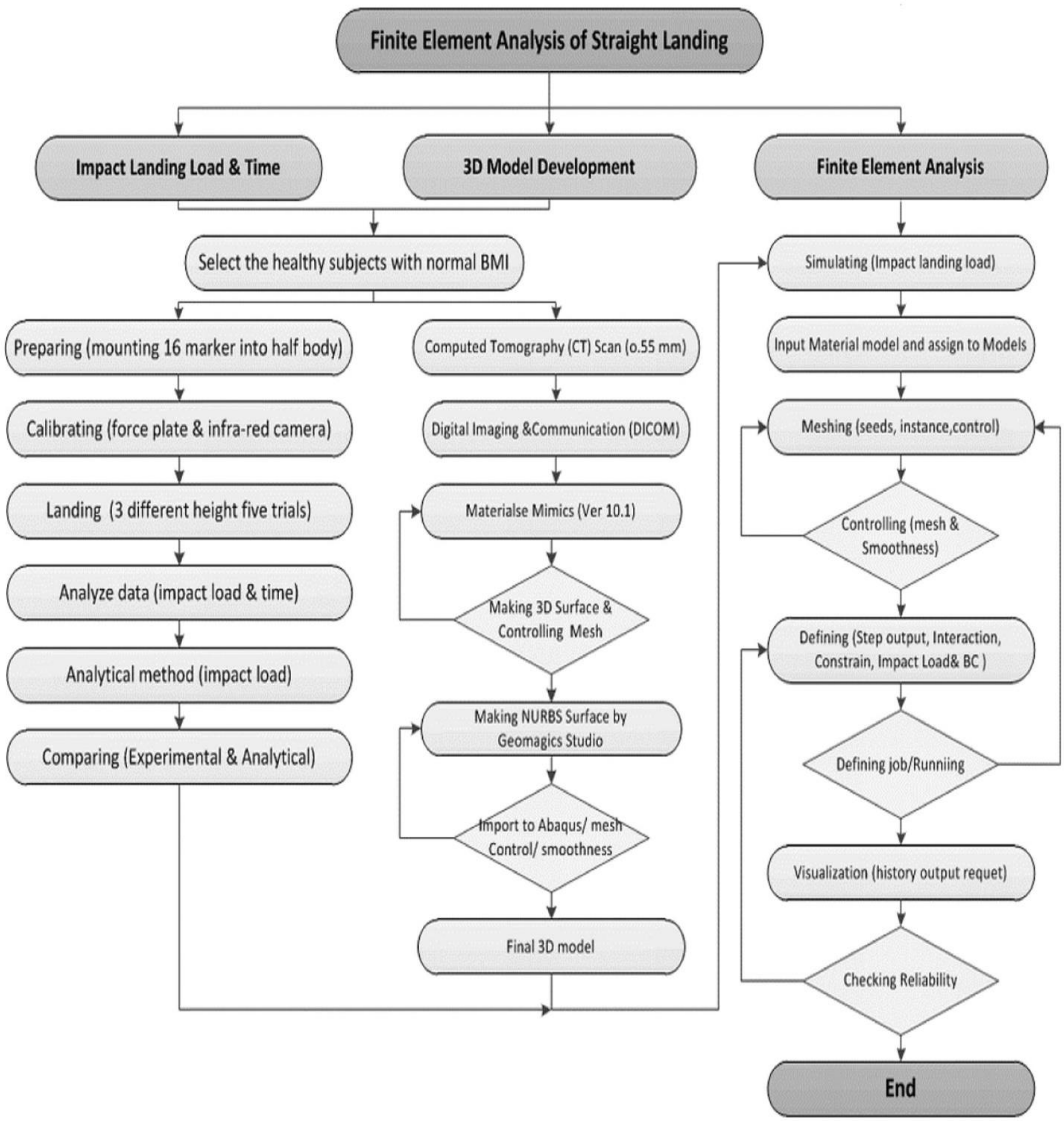


Fig 3.1 FEA analysis flow chart

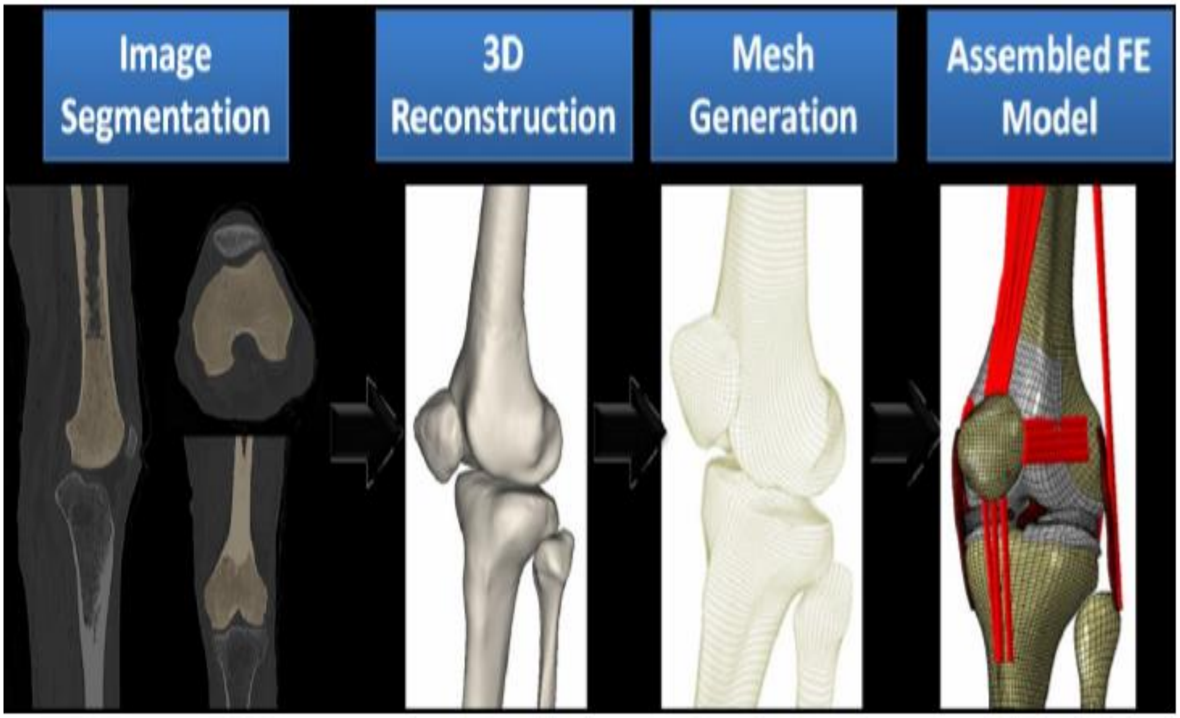


Fig 3.2 Construction of FE model of knee joint

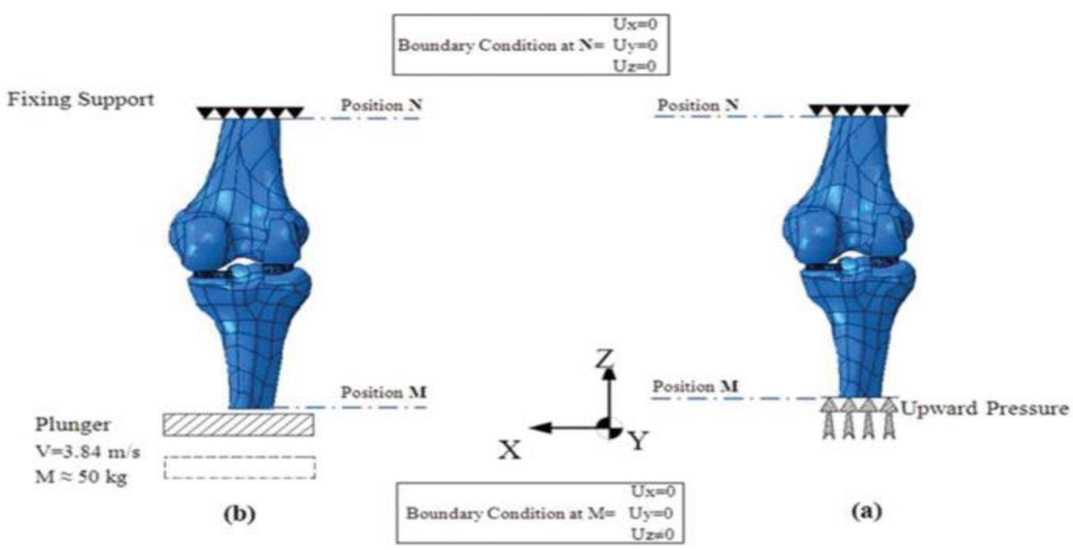


Fig 3.3 Maximum penetration of knee, 3.3a distance before landing 3.3b after landing

DIFFERENT ASSEMBLY OF 3D KNEE JOINT

It shows, anterior and posterior views of knee joint in Mimics. The 3D models were exported to 3D-matic software. In 3D-matic, the number of triangles is reduced and the aspect ratio of is improved so it shows suitability of the mesh for finite element analysis.

The mesh is generated by using Solid elements method in Ansys software. SOLID element is a best resolution 3-D element, it has 10 nodes, and every node has 3 translation direction x, y and z and quadratic displacement behavior.

It is suitable for regular and irregular modelling meshes. The meshed models are exported to ANSYS Workbench. The number of nodes and elements used for the model is 116,616 and 52,951. The menisci, cartilage, ligaments and bones are assumed to be isotropic and linearly elastic. The material properties of the knee joint are shown below.

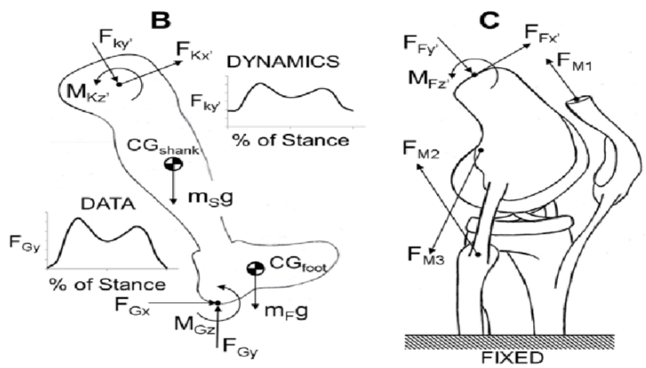


Fig 3.4 solid geometry of knee

My analysis is mainly based on macroscopic part like femur and tibia stress analysis, basic properties of knee material has been shown in table 1.

Material	Young modulus (MPa)	Poisson ratio (MPa)	Bulk modulus (MPa)	Shear modulus (MPa
Femur	17,000	.3	14,167	6538.5
Tibia	14,000	.3	11,667	5384.6
Cartilage	5	.46	20.833	1.7123
Menisci	59	.49	983.33	19.799

Table 1

The contact between femur and tibia is represent the contact between cartilage and bone, ligament and bone, and the medial collateral ligament to the medial meniscus.

Separation contact we cannot defined between the tibial cartilage and femoral cartilages, in between cartilages and menisci and the patellar cartilage and femoral cartilage. Flexion-extension are constrained for the femur to analyze the knee joint extension. The fibula and tibia are constrained at the lower surfaces. A compressive (vertical) force of 1400 N applied to the top surface of the femur, it matches with the force of the full extension position.

The finite element and knee joint model with boundary conditions we can see below. FEA of the joint (knee) performed with the discussed boundary conditions (BC). The full model Contact stresses were calculated but my main focus is on the femur, menisci and tibial cartilage which is necessary.

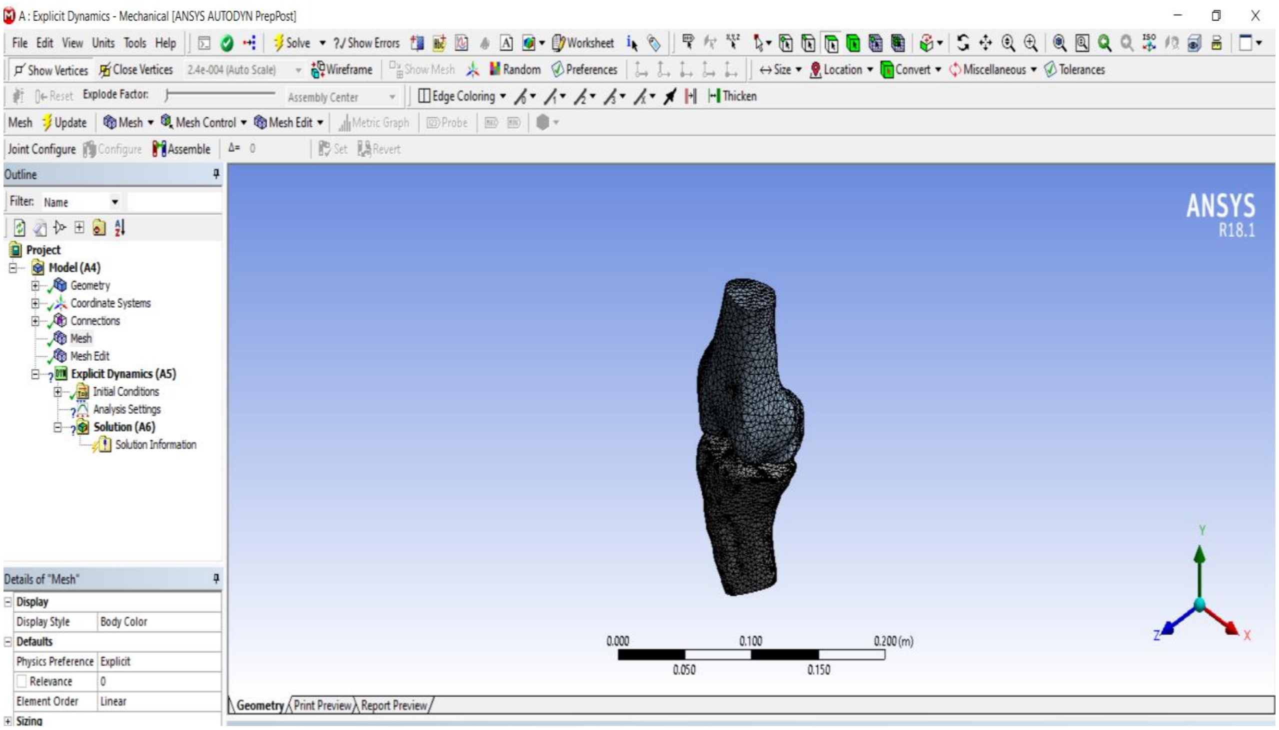


Fig 3.5 meshed knee joint

During free landing applied load on the feet varies. This load varies according to the ground condition, Height from the ground, landing direction, and position. These Three different landing positions shown below. Height increases the magnitude of load also increases. Taking there is a significant difference between impact and falling from a height. Time for analysis is .04 sec have been taken. and the total time to land is 20 sec. Landing time may be added to 5 sec. Height of 75cm estimated when subject velocity is free fall.

$$V^2 - V_0^2 = 2gx$$
$$V(t) = \sqrt{2x9.806\,x0.75}$$
$$V = 3.835 m/_{s}.$$

Average impact time is .04sec

$$\int_0^t F dt = \int_0^{3.835} m dv$$
$$F = 6136N.$$

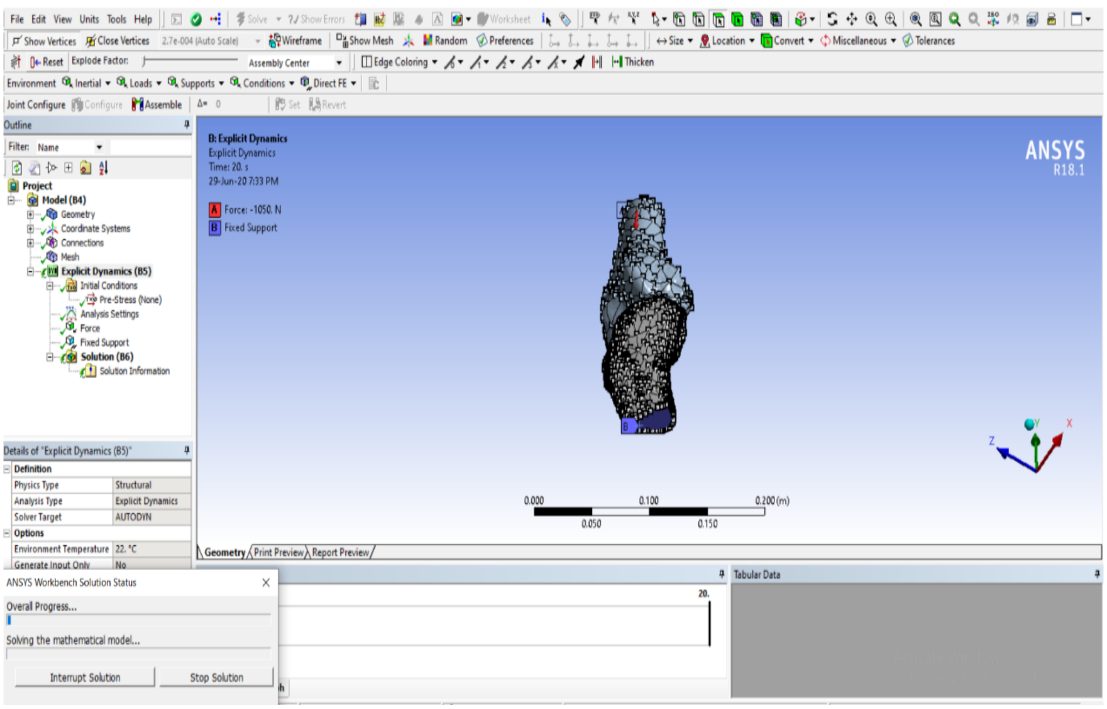


Fig 3.6 meshed knee joint and loading condition

Tibia meshing is done and tibia have total 12288 elements, lower part of tibia restricted which is zero in all direction. 1400 N load has been applied on it and distributed all over the tibia.

Femur meshing of femur was done by using ansys software, total 21263 elements and 1400N load applied, femur simply supported and this load imposed all nodes of femur. Out of 10 nodes 8 nodes restricted, UX is equal to zero and UZ also zero to avoid translation.

Menisci total meshed element is 2734 and it is simply supported in lower part. 1400 N load applied and load distributed all over the nodes of menisci. X, Y direction is free but Z direction is restricted equal to zero.

My focus is mainly based on analysis of stresses like, the Von-Misses Stress (VMS) and maximum and minimum Principal Stress. The maximum compressive stress of 3.3MPa and the maximum VMS of 2.91MPa are located on the back portion of the femoral cartilage.

1. The magnitudes of principal stress of 3.3MPa and VMS of 5.2MPa maximum on the medial meniscus as compared to the lateral meniscus with 2.91MPa and 2.0MPa.

2. At lateral femoral cartilage compressive stress is -13.3MPa which is greater than the medial cartilage which is -6.6Mpa.

3. Tibial cartilage depicted compressive stress, Knee joint Cartilage provide impact force in upward direction. That is the reason these components absorbed greater impact.

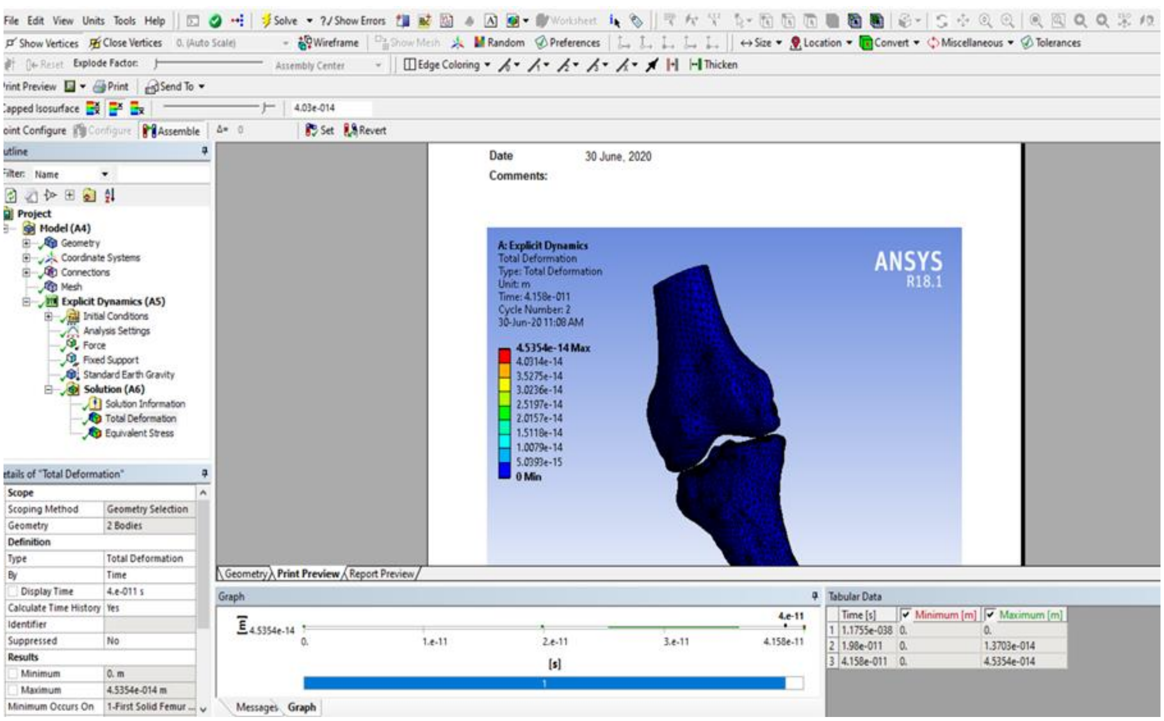


Fig 3.7 Forces on Tibia and Femur.

4. On medial Cartilage peak nodal value is modulus value of the meniscus is approx. eleven times cartilage value.
5. Deformation of cartilage must be more than that of meniscus impact load.
6. The Meniscus contact area is greater. And the maximum value is 55.66 and 8.97MPa.

Force of 1400m per sec applied of Femur to check the stability of joint.

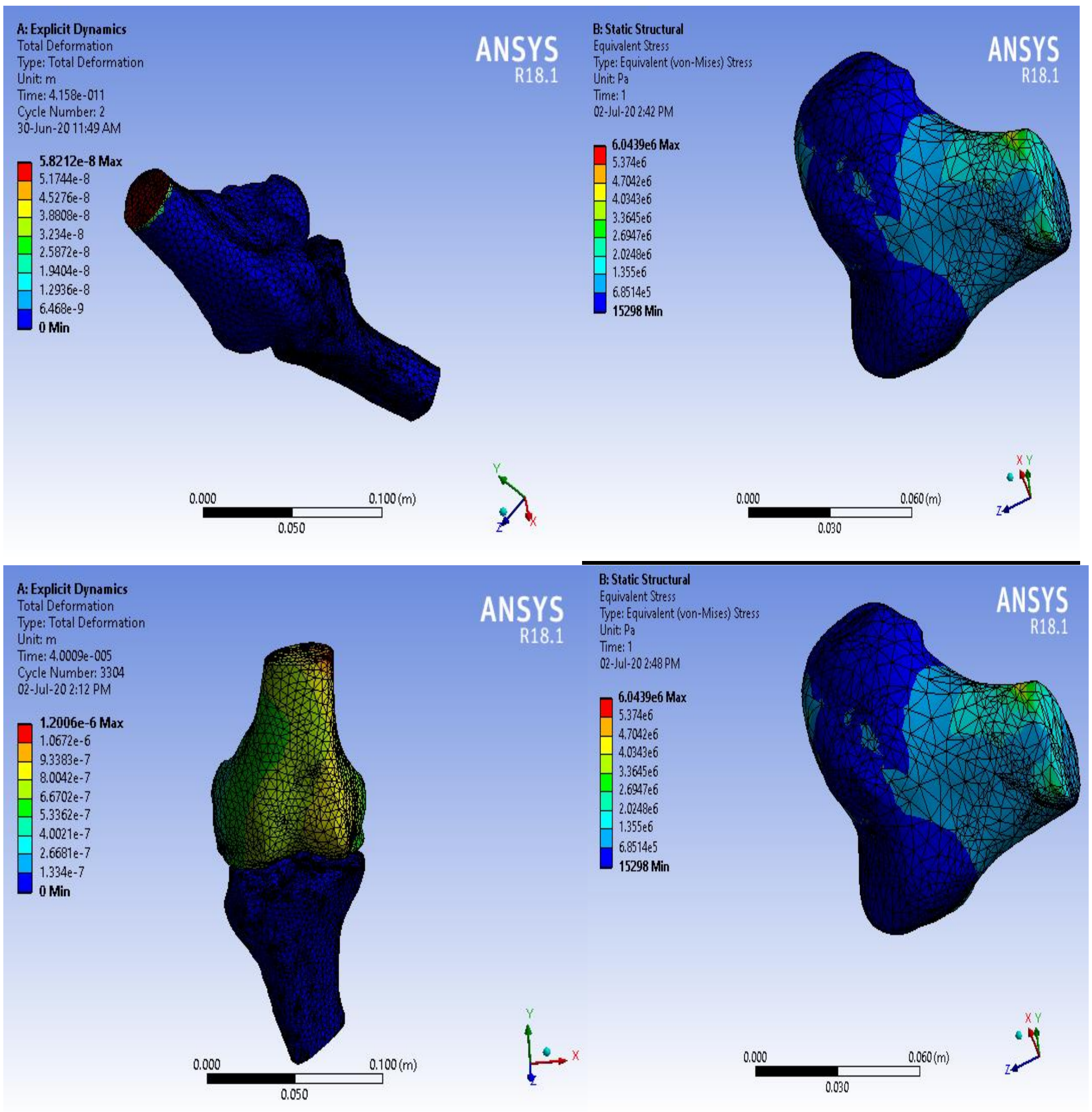


Fig 3.8 load applied on knee joint

Figure shows, the maximum principal stress distributions on the femoral cartilage, menisci and tibial cartilages.

Show the VMS distributions on the Femur, Tibial and Patella

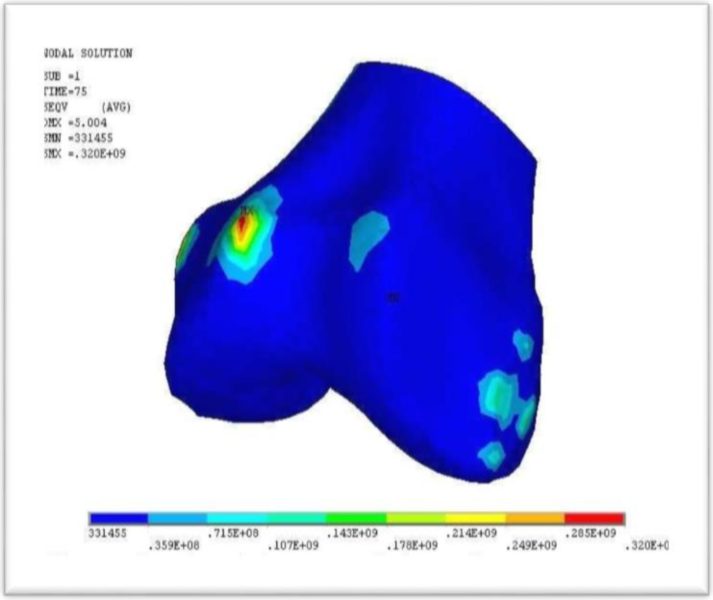


Fig 3.9 Femur Stresses and result

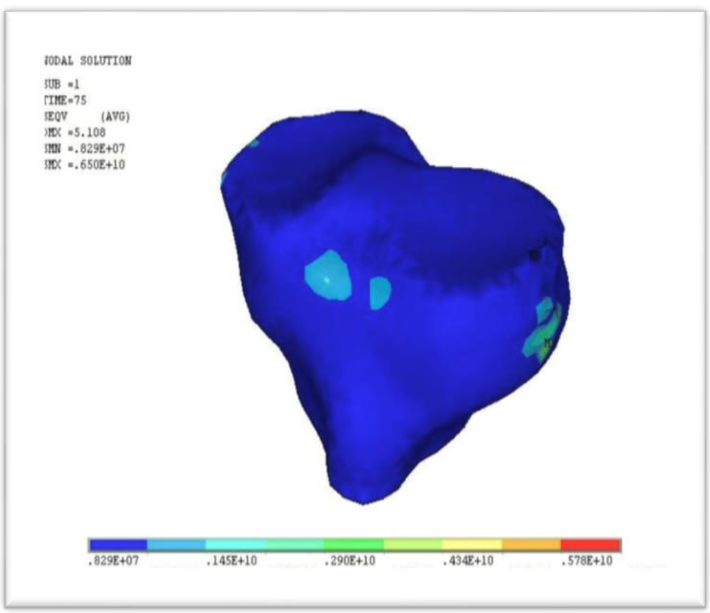


Fig 3.10 Tibial Stresses and result

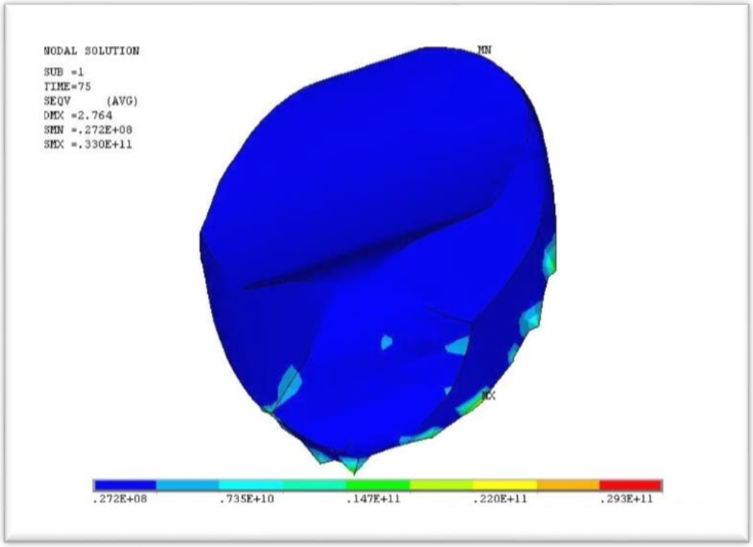


Fig 3.11 Patella Stresses and result

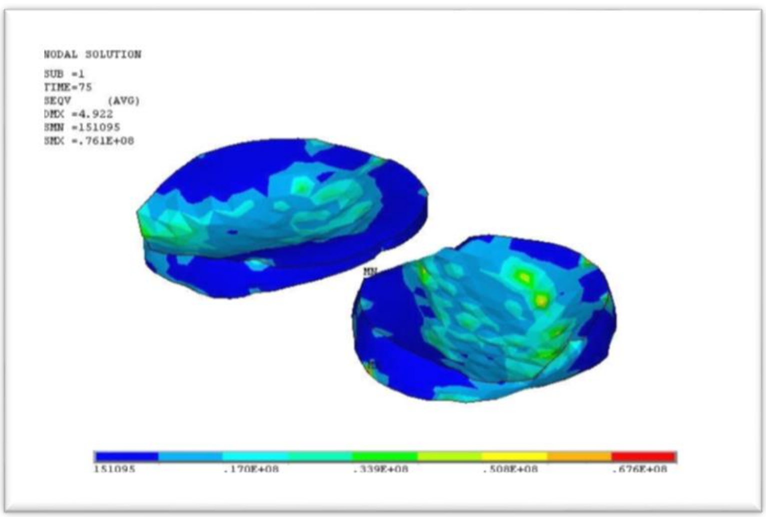


Fig 3.12 Menisci Stresses and result

CHAPTER-5

RESULT AND DISCUSSION

A 3 Dimensional model of the knee joint was constructed in the mimics' software and analyzed with the FEA. An axial compressive force applied on the joint.
The main objective is to find out the contact stresses by using finite element analysis (FEA). Many research paper, they have used FEA to analysis of the compressive stresses in the healthy volunteer knee joint. Impact of knee when free fall on ground and flexion and extension, muscles play very important role and it anchored on the top of patella. Patellar tendon act in downward direction. A 3 Dimensional model of the knee joint was constructed in the mimics' software and analyzed with the FEA. An axial compressive force applied on the joint. The main objective is to find out the contact stresses by using finite element analysis (FEA). Many research paper, they have used FEA to analysis of the compressive stresses in knee joint. The menisci of knee varied between 0.98 MPa in compressive stress in the externally is 3.96 MPa and the internally, under a compressive force of 1300 N. Author Dong,found a compressive stress on both the lateral and medial meniscus is 3.00 and 2.83 MPa. Pena et al. were found that the compressive stress on the medial meniscus was 3.31 MPa. The compressive stresses on the lateral and medial meniscus was found on 3.5 MPa and 2.1 MPa. The difference in the value of stress, due to that frictionless nonlinear contact between the tibial and femoral cartilage, menisci and cartilage between the patellar and femoral cartilage is not considered. Normal active extension free fall is of the legs depends
In below table, explained stresses at different-different plane.

	Femur(MPa)	**Tibia(MPa)**	**Patella(MPa)**	**Menisci(MPa)**
Avg value	261.237	607.005	100.215	11.1417
X Direction	3.3377	4.9664	1.2575	.0158547
Y Direction	3.4754	7.40566	3.1142	.0681978
Z Direction	2.7584	17.7663	7.403	.00249752

Table 2. Results

1 The menisci of knee stress varied between .00249MPa to .015MPa under compressive force of 1300 N.
2 Dong et al. found a compressive stress on the lateral and medial meniscus of 3.00MPa and 2.83MPa.
3 Pena et al. were found that the compressive stress on the medial meniscus was 3.31MPa. The compressive stresses on the lateral and medial meniscus was found on 3.5MPa and 2.1MPa.

4 The difference in the value of stress, due to that frictionless nonlinear contact between the tibial and femoral cartilage, menisci and cartilage between the patellar and femoral cartilage is not considered.

	Femur(MPa)	**Tibia(MPa)**	**Patella(MPa)**	**Menisci(MPa)**
Avg value	247.895	527.8765	142.215	11.1417
X Direction	2.7370	3.8750	1.2575	.0158547
Y Direction	2.9813	5.98676	3.1142	.0681978
Z Direction	2.0235	15.12654	7.403	.00249752

Table 3. Results based on Experimental data in different conditions

5 Different values of stress in different coordinate is shown in above table, Femur stresses varies from 2.6MPa to 2.7MPa. In Tibia 4.9MPa to 17.9MPa, and in Patella value of stresses is 1.2MPa to 7.4MPa.

CHAPTER 6.

CONCLUSIONS AND FUTURE SCOPE

A 3 Dimensional model of the healthy volunteer knee joint built in mimic software, it has bones and soft tissues both like, Cartilages, tendons, ligaments, menisci and bones. And analyzed under compressive force. The force of full flexion position. The analysis of final model compared with the literature results which is fully established, which was true and based on actual and room based practical. From above discussion, observed that, the contact between the tibial cartilage and femoral cartilages was built. The high load bearing and low load-bearing area were situated on the anterior and posterior part of the femoral cartilage. This analysis shows that medial meniscus is to rupture as stresses in the medial menisci are more as compare to lateral one. Modelling of 3 dimensional human knee joint in mimics' software is very useful for kinematic and dynamic analysis of knee joint on FEA or finite element analysis. To avoid complexity in the Analysis, all the assumptions taken from previous research work, Present work is thoroughly based on analysis of Knee joint including stresses and Friction. Explained each and everything about forces and Boundary conditions, which was main objective. Obtained results can be modified including reaction forces and stresses by analyzing it with other parameters.

FUTURE SCOPE

1. Artificial Knee replacement success rate nowadays is about 90 to 92 percent it happened because of improvement of surgical technique, though we can prognosis any potential defect/weakness, ultimately leading to the failure of the concerned body part.
2. So we could see the importance of bio mechanics in our life, whether it is related to machines or human being. Scientist "hetzes" said Bio mechanics is the study of the movement of living things.
3. To know about stresses on knee, by applying "Multibody" simulation given by Author Adoms, for compare results and stresses. This method also based on FEA Dynamic Analysis.
4. Modelling of 3 dimensional human knee joint was built in mimics' software is very useful for kinematic and dynamic analysis of knee joint on FEA or finite element analysis.

In The thesis, a 3 dimensional model is used for simply stress analysis on knee joint including femur and tibia.

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