Numerical Analysis of Fractured Femur Bone with Prosthetic Bone Plates

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Abstract

Bones are living tissues, consists of minerals like calcium and phosphorus. They grow rapidly during one's early years and renew themselves. The bone is considered as a linear-elastic, isotropic and homogeneous material. Bones are the essential part of the human skeleton. It helps to support the softer parts of the body. Trauma is a major cause of death and disability in both developed and developing countries. The World Health Organization (WHO) predicts that by the year 2020, trauma will be the leading cause of years of life lost for both developed and developing nations. Bone fracture is one of the common trauma. One method of curing the fractured bone is by joining the fractured bone by using bone plates. The objective of this study is to compare bone plates made of different biomaterials (Stainless Steel, Titanium, Alumina, Nylon and PMMA) and find out the best material. Femur bone is modelled in SOLIDWORKS and analyzed using ANSYS. The fracture fixation plates are also modelled and fixed to a fracture bone and analyzed.

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1. Introduction

Origins of biomaterials date back thousands of years; as archaeologists have found that metal dental implants have been used in 200 A.D. However they have been developed significantly after World War II.

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Today, biomaterials are defined as “artificial or natural materials used in the manufacturing structures for replacing the lost or diseased biological structure to restore its form and function”. A biomaterial can exhibit specific interactions with cells that will lead to stereotyped response. Performance of biomaterials is controlled by two characteristics of bio functionality and biocompatibility.

**Nomenclature**

| Symbol | Definition           |
|--------|----------------------|
| ρ      | Density              |
| E      | Young’s Modulus      |
| γ      | Poisson Ratio        |
| G      | Shear Modulus        |
| σ_{eq} | Equivalent stress    |
| δ      | Directional deformation |

**Prosthesis**

Prosthesis is a device that replaces a missing body part. It is part of the field of bio mechatronics, the science of using mechanical devices with human muscle, skeleton, and nervous systems to assist or enhance motor control lost by trauma, disease, or defect. Prostheses are typically used to replace parts lost by injury or missing from birth or to supplement defective body parts. Inside the body, artificial heart valves are in common use with artificial hearts and lungs seeing less common use but under active technology development. Other medical devices and aids that can be considered prosthetics include hearing aids, bone plates, artificial eyes, palatal obturator, gastric bands, and dentures.

![Fig. 1. (a) Prosthetic hip joint; (b) Prosthetic teeth.](image)

1.2 Human Bone

Bones are rigid organs that constitute part of the endoskeleton of vertebrates. They support and protect the various organs of the body, produce red and white blood cells and store minerals. Bone tissue is a type of dense connective tissue. Bones come in a variety of shapes and have a complex internal and external structure, are lightweight yet strong and hard, and serve multiple functions. One of the types of tissue that makes up bone is the mineralized osseous tissue, also called bone tissue that gives it rigidity and a coral-like three-dimensional internal structure. Other types of tissue found in bones include marrow, endosteum, periosteum, nerves, blood vessels and cartilage. At birth, there are over 270 bones in an infant human's body, but many of these fuse together as the child grows, leaving a total of 206 separate bones in an adult.

1.3 Femur

The femur or thigh bone, is the most proximal (closest to the center of the body) bone of the leg capable
of walking or jumping, such as most land mammals, birds, many reptiles such as lizards, and amphibians such as frogs. In vertebrates with four legs such as dogs and horses, the femur is found only in the rear legs. The femur is the largest bone in the human body. By most measures the femur is one of the strongest bones in the body. The femur is the longest, heaviest and by most measures the strongest bone in the human body. Its length is 26% of the persons height, a ratio that is useful in anthropology because it offers a basis for a reasonable estimate of a subject's height from an incomplete skeleton. The upper or proximal extremity (close to the torso) contains the head, neck, the two trochanters and adjacent structures. The body of the femur (or shaft) is long, slender and almost cylindrical in form. It is a little broader above than in the center, broadest and somewhat flattened from before backward below. It is slightly arched, so as to be convex in front, and concave behind, where it is strengthened by a prominent longitudinal ridge, the linea aspera which diverges proximal and distal as the medial and lateral ridge. The lower extremity of the femur is larger than the upper extremity. It is somewhat cuboid in form, but its transverse diameter is greater than its antero-posterior (front to back). It consists of two oblong eminences known as the condyles.

1.4 Prosthetic bone plates

Bone plates are surgical tools, which are used to assist in the healing of broken and fractured bones. The breaks are first set and then held in place using bone plates in situations where casts cannot be applied to the injured area. Bone plates are often applied to fractures occurring to facial areas such the nose, jaw or eye sockets. Repairs like this fall into an area of medicine known as osteosynthesis.

![Fractured bone with plate](Fig. 2. Fractured bone with plate)

2. Selection of Materials

The biomaterials I have selected for this study are
- Stainless steel
- Titanium
- Alumina
- Nylon
- PMMA

| Material     | ρ (g/cm³) | E Gpa | γ    |
|--------------|-----------|-------|------|
| Stainless Steel 316L | 8000      | 193   | 0.30 |
| Titanium      | 4430      | 895   | 0.342|
| Alumina       | 8.5       | 240   | 0.31 |
| Nylon         | 3.72      | 300   | 0.21 |
| PMMA          | 1.18      | 2.2   | 0.20 |
3. Modelling and Analysis of Femur bone

The human femur bone was modelled using Solidworks Software. The dimensions for modelling the bone was refered in the Journal [3]. The analysis of human bone is done by using ANSYS WORKBENCH®. The femur bone modelled using SOLIDWORKS is shown in Fig. 3. The steps involved in analysis are explained below.

3.1 Material Assignments

Human bone is highly heterogeneous and nonlinear in nature, so it is difficult to assign material properties along each direction of bone model. Material can be assign in two ways, either in Mimics or in Finite element module. Here material properties are directly assigned in ANSYS. The following properties of Density, Young’s Modulus and Poisson’s Ratio are used as 2000 Kg/m3, 2.130 GPa and 0.3 respectively for analysis.

3.2 Import of Geometry

The file created using the SOLIDWORKS software is saved in .IGS format. It is imported to the ANSYS software Then generate option is clicked. Now the model is ready for analysis. The imported geometry in ANSYS is shown in Fig. 4.
3.3 Meshing

After creating model, for further Finite element analysis (FEA), surface mesh is generated for femur bone model. The size of the mesh is given as fine mesh. The number of nodes and elements created are 40397 nodes and 23353 elements. The meshed model of the Femur bone in ANSYS is shown in Fig. 5.

3.4 Boundary conditions

Femur bone is solid and inflexible. The three dimensional Finite element model of femur bone with volumetric mesh was imported in ANSYS. An eccentric and concentrate load of 750 Pa applied at the head of femur bone and fixed support is provided at lateral condyle, medial condyle and patellar surface i.e. lower surface. The boundary conditions given for the femur bone in ANSYS is shown in Fig. 6. The material properties of the femur bone is given as per the Table 2.
Table 2. Mechanical properties of Femur Bone.

| Material | Bone |
|----------|------|
| $\rho$   | 2000 g/cm³ |
| $E$      | 2.13 GPa   |
| $\gamma$| 0.3        |
| $G$      | 70 MPa     |

3.5 Results & Discussions

This study investigates stress distribution, total deformation and fatigue failure of femur for a weight of 75 Kg male during normal position. For eccentric load maximum Directional deformation 0.000040462m was obtained. Results shows that higher deformation occurs at the head of femur and lowest occur at the lower end. Maximum equivalent stress 65345 Pa and Minimum principle stress is 35.98 Pa. Maximum principle stress is generated at the middle section of the femur. The equivalent (Von Misses) stress 65345 Pa occurs.

![Fig. 7. Equivalent stress of femur bone](image)
Fig. 8. directional deformation of femur bone

4. Analysis of fractured femur bone joined with bone plates

Bone plate for the femur bone is modelled by using SOLIDWORKS software. The dimensions for this bone plate are referred by buying a femur bone plate made of SS316L. In future during the experiment this kind of bone plate is to be fabricated. The bone plate for the fractured femur bone modelled in SOLIDWORKS is shown in Fig. 8.

The femur bone that was modelled previously is broken into two pieces. The bone plate and the broken femur bone that are assembled by using the SOLIDWORKS software. They are joined by a screw that is also modelled in SOLIDWORKS software. Then the assembled model is imported to ANSYS software and the analysis is done. The procedure for analysis is same as that of the previous femur analysis. But a change is that, here two materials are being used and so that material properties are assigned for both the materials. Bonded joint is given for joining the bone and friction joint is given for joining the screws with the plate. The fractured femur bone
joined with bone plate is shown in Fig. 9.

Fig. 10. Assembly of broken bone and plate using SOLIDWORKS

Then the assembled model is imported to ANSYS software and the analysis is done. The procedure for analysis is same as that of the previous femur analysis. But a change is that, here two materials are being used and so that material properties are assigned for both the materials. Bonded joint is given for joining the bone and friction joint is given for joining the screws with the plate.

Fig. 11. Equivalent stress of femur with titanium plate assembly;
Table 3. Finite Element Results

| Material         | $\sigma_{eq}$ (pa) | $\delta$ (m) |
|------------------|--------------------|--------------|
| Stainless Steel 316L | 3.2906e6          | 0.0061501    |
| Titanium         | 3.2568e5           | 4.851e-7     |
| Alumina          | 1.8259e6           | 0.0063721    |
| Nylon            | 5.0434e6           | 0.0051529    |
| PMMA             | 5.3459e6           | 0.0059465    |

5. Conclusion

In this project femur bone is modelled and analysed. Then five different materials for fabricating bone plates are selected. Bone plate is modelled and this plate is used to join a broken femur bone. Analysis is done on the assembled model. By doing so the material having a less effect of stress due to loading is found out. In the materials used titanium is found out to have less equivalent stress. Further work has to be done to find the best material based on comparison of stiffness between bone and plates, corrosion and wear resistance of the materials. By doing so the best material for manufacturing bone plate will be found finally.

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