# Finite Element Analysis of Existing and Modified Intramedullary Rod for Orthopedic Applications

J. UDAYA PRAKASH*, [1], S. JAYAVELU[1], C. RAJKUMAR[1]

*Corresponding author
[1]Department of Mechanical Engineering,
Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology,
Chennai, India,
udayaprakashj@veltech.edu.in*, sjayavelu@veltech.edu.in, coa@veltech.edu.in

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***Abstract**: Finite Element Analysis (FEA) has been used in the field of biomedical engineering and especially in biomechanics, which helps to predict and validate feasible designs for complex cases. The role of biomechanics has grown steadily in the field of orthopedic surgery. For example, fixation was performed to stabilize a large femoral bone fragment. Femoral injury is analyzed in real time, and the experiment provides a three-dimensional visualization of finite elements designed to explain the mechanical properties of the femur. Modified trapezoidal nail shape is used in the modified intramedullary rod setup in order to obtain additional strength and stability. It also provides resistance to femoral head rotation. Potentially it improves patient mobility and recovery since the modified design is in par with the anatomy of the human femur bone.*

***Key Words:** Biomechanics, Femur, Finite Element Analysis, Intramedullary rod, Orthopedics*

## 1. INTRODUCTION

Finite Element Analysis (FEA) has evolved in biomedical engineering and especially in biomechanics, helping to predict and validate feasible designs for complex cases (Bhat et al., 2006 [2]). Biomechanics applies the laws of physics and mechanical principles in living organisms. FEA is a widely accepted tool for simulating the structures producing results in faster and efficient manner (Cheung et al., 2004 [3]). Femur bone is the human skeleton's longest and most strong bone. This consists of irregular geometry, complex biological tissue microstructure. Bone tissue is part of the thick hard tissue of the connective. Bones consist of inorganic salts in a collagen, protein and mineral matrix (Tai et al., 2009 [12]).

Normally, bones retain the body shape and aid in the transmission of force during movement. The Femur bone is the strongest only under compression loading. The femur bone is the shaft that connects hip joint to knee joint. Femur holds most of the upper body weight of humans in normal conditions (Christensen et al., 2000 [4]).

With the minimal inputs available, the finite element model would be useful to supplement experimental work and to address the inherent limitations of experimental studies (Jebarose et al., 2017 [7]). Femur fractures are very different. The bone fragments can be aligned correctly and the fracture can be sealed (skin intact) or open (bone penetration through the skin). The fracture is considered an open or composite fracture if a bone fractures in such a way that bone fragments stick out through the skin or a wound penetrates deep into the broken bone (Wille et al., 2012 [14]). The underlying muscles, tendons and ligaments are also much more affected by open fractures.

We have a higher risk of complications, especially infections, and it takes longer to heal (Jonkers et al., 2008 [8]). When a broken bone penetrates the body, urgent treatment is needed, and often an operation is needed to clean the fracture area. In addition, when a fracture is exposed to the skin due to the risk of infection, there are more problems associated with healing. High-energy incidents such as car crashes, falls, and sports injuries usually cause open fractures (Amornsamankul et al., 2010 [1]).

During extreme fractures happening in human legs, the femur bone is damaged causing the inability to walk or perform normal human activities. As a measure of improving the chances of carrying out normal human activities the intramedullary rod is placed as fixation method (Tommasini et al., 2005 [13]). These methods help the human to walk, to climb steps, to move his legs or run like a normal human being but with certain limitations (Giladi et al., 1991 [5]). At present the intramedullary rod (IR) used are of circular cross section and based on the diameter of the human bone.

The Intramedullary rod provides strength and support to femur bone when an open ended fracture happens (Simoes et al., 2000 [10], Grassi et al., 2012 [6]). This paper deals with the design modification of the intramedullary rod setup to improve the rotational stability. It provides anatomically shaped design instead of conventional circular cross section. The circular cross section sometimes requires bone grafting to accommodate the intramedullary rod (Juszczyk et al., 2011 [9], Sverdlova et al., 2010 [11]). The CAD data for modeling the human femur bone is obtained from the CT scan data and model is created using PRO-E Creo software. For meshing and carrying out the analysis of Femur and the intramedullary rod, HYPERWORKS 12.0 and OPTISTRUCT packages were used. The Finite Element Analysis helps in carrying out static analysis to figure out the stress distribution and the deformation of present circular cross sectional rod and the modified trapezoidal shape.

## 2. RESEARCH METHODOLOGY

The methodology of the research work is shown in Figure 1. It is also known as the Process Flow Diagram.

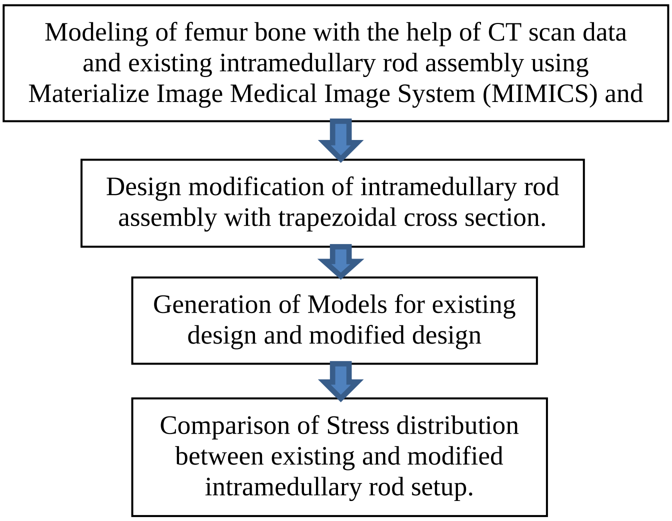

Figure 1. Research Methodology

## 3. MODELING OF INTRAMEDULLARY ROD ASSEMBLY

The 3D CAD model was generated using Pro-E Creo for a normal human with complete growth. Figure 2 shows the femur bone.

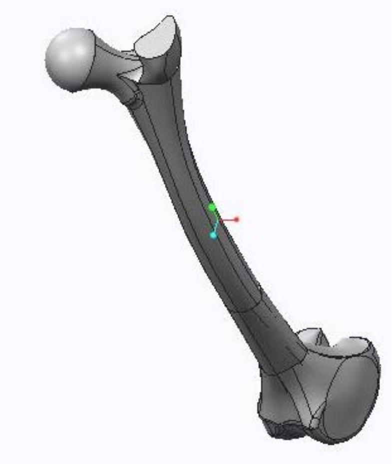

Figure 2. Schematic Diagram of Femur Bone

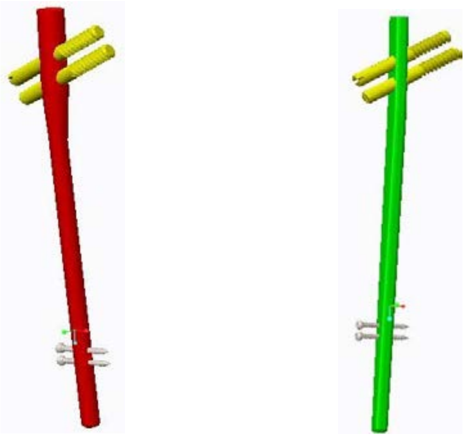

Figure 3. Present and Modified Intramedullary Rod Assembly

Today, titanium, cobalt chrome, zirconium and stainless steel 316 are the most widely used biomaterials for internal fixing devices due to the favorable combination of mechanical properties such as resistance to oxidation relative to other metal implants. For decades, stainless steel implant biocompatibility has been shown to be a successful human implantation. To ensure adequate resistance to corrosion, non-magnetic reaction and mechanical properties, the metallurgical requirements for these biomaterials are stringent. Stainless steel screw twisting properties vary from those of titanium screws. Stainless steel bone screws are easier to handle as they are more resistant to corrosion. First, the three-dimensional model is built the same as in real-time situation for FE analysis of intramedullary rod setup. The femur bone considered for the study is obtained from a male cadaver of age 24 years. The weight of the body is 70 Kg. Based on the scan data the bone is modeled in modeling software Pro-E Creo (Figure 3 & 4).

Figure 4. Top View of Present and Modified Intramedullary Rod Assembly

## 4. FEMUR BONE STUDY

### 4.1 Meshing

After developing the three-dimensional design, surface mesh for femur bone and intramedullary rod was created separately and assembled again for further Finite Element Analysis. The Femur bone and intramedullary rod is modeled as tetrahedral elements and the screws are modeled as one - dimensional beam elements. Rigid elements are used to connect the beam, intramedullary rod and the femur bone. The assembly is done based on the real time connection data.

### 4.2 Assignment of Resources

Human bone in fact is heterogeneous. In HYPERMESH, product properties are delegated directly. The following properties are used for measuring Density, Young's Modulus and Poisson's Ratio as 2000 Kg / $m^3$, 2.130 GPa and 0.3.

### 4.3 Boundary Conditions

Femur is a thigh bone that both left and right femurs bear the entire weight of the human body evenly. We looked at the actual body weight of 65 Kg, 70 Kg and 75 Kg in our analysis. The load is 637.65 N, 686.70 N and 735.75N, respectively, to be shared equally between two femur bones. Therefore, the load of 318.825 N, 343.35 N and 367.875 N is added to the right femur bone, which is the half of the entire body weight. A fixed support is provided for the lateral condyle, medial condyle and patellar surface as shown in Figure 5.

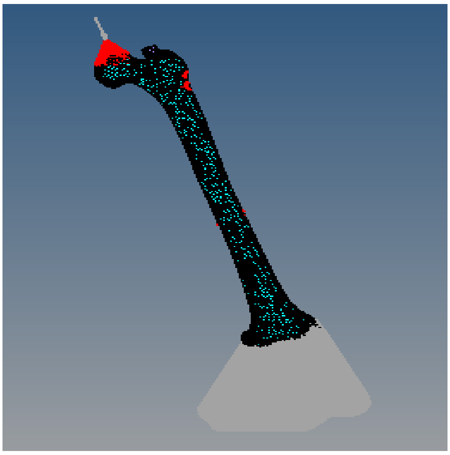

Figure 5. Application of Constrains

### 4.4 Analysis

The load is applied to the head of the femur bone and the linear static OPTISTRUCT analysis is performed and the map of deformation and the pressure distribution of Von Mises were obtained. Deformation for existing and modified intramedullary rod setup in femur bone assembly is shown in figure 6, figure 7 and figure 8. Deformation observed for 318.825N load of existing and modified intramedullary rod setup is shown in figure 6.

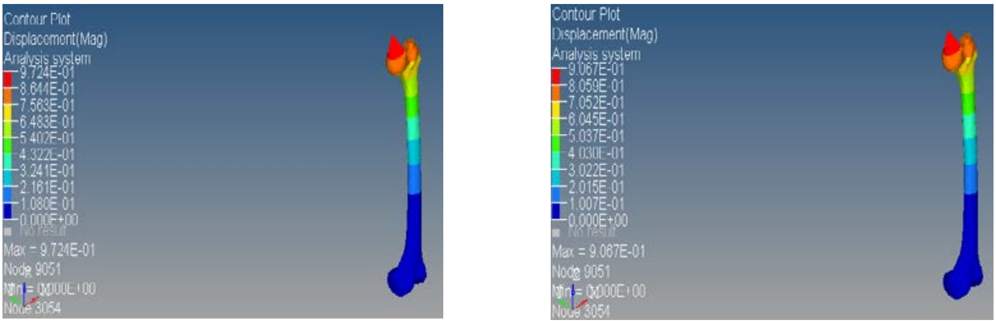

Figure 6. Deformation of existing and modified intramedullary rod setup for 318.825N load

Deformation observed for 343.35 N load of existing and modified intramedullary rod setup is shown in figure 7.

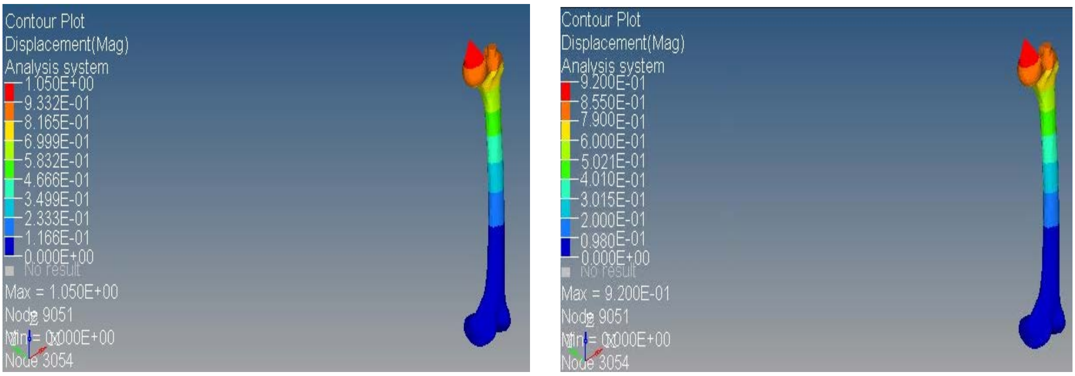

Figure 7. Deformation of existing and modified intramedullary rod setup for 343.35 N load

Deformation observed for 367.875 N load of existing and modified intramedullary rod setup is shown in figure 8.

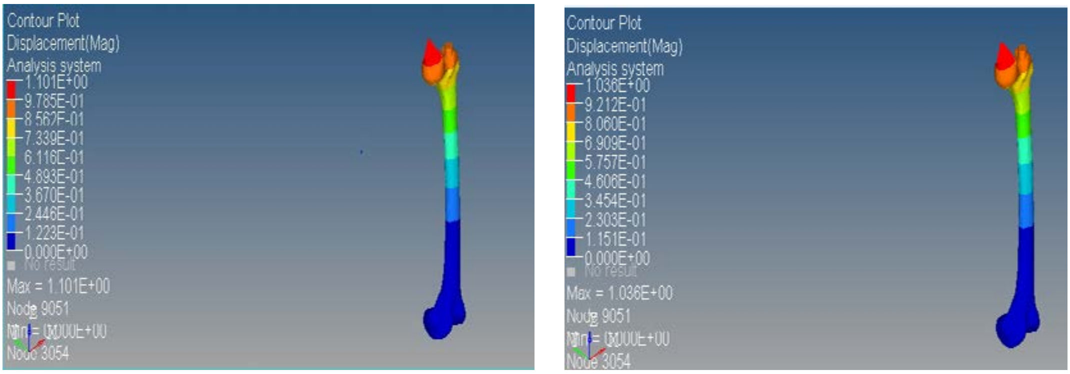

Figure 8. Deformation of existing and modified intramedullary rod setup for 367.875 N load

Von Mises Stress patterns observed for 318.825 N load of existing and modified intramedullary rod setup is shown in figure 9.

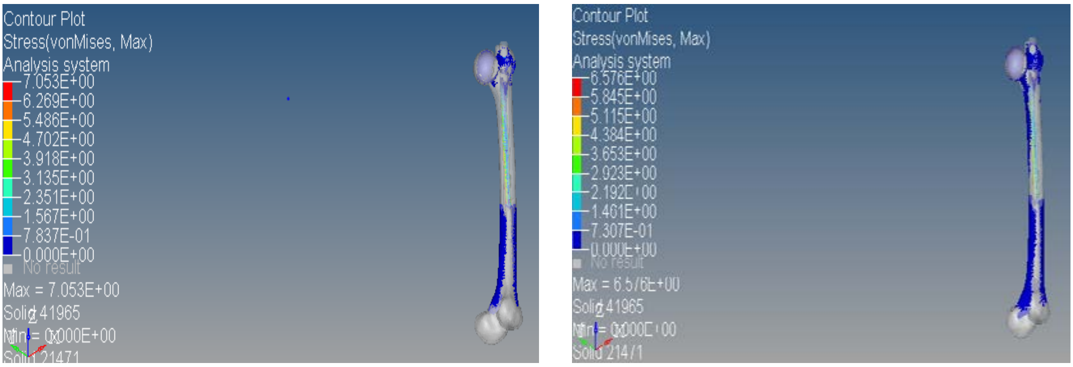

Figure 9. Stress Patterns of existing and modified intramedullary rod setup for 318.825N load

Von Mises Stress patterns observed for 343.35 N load of existing and modified intramedullary rod setup is shown in figure10.

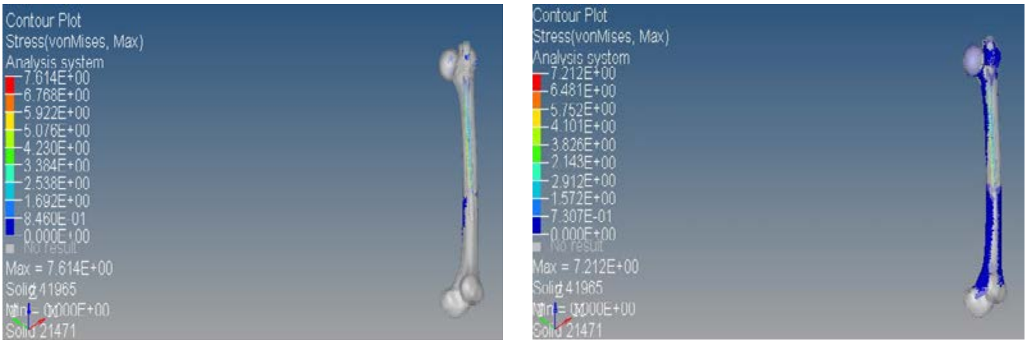

Figure 10. Stress Patterns of existing and modified intramedullary rod setup for 343.35 N load

Von Mises Stress patterns observed for 367.875 N load of existing and modified intramedullary rod setup is shown in figure 11.

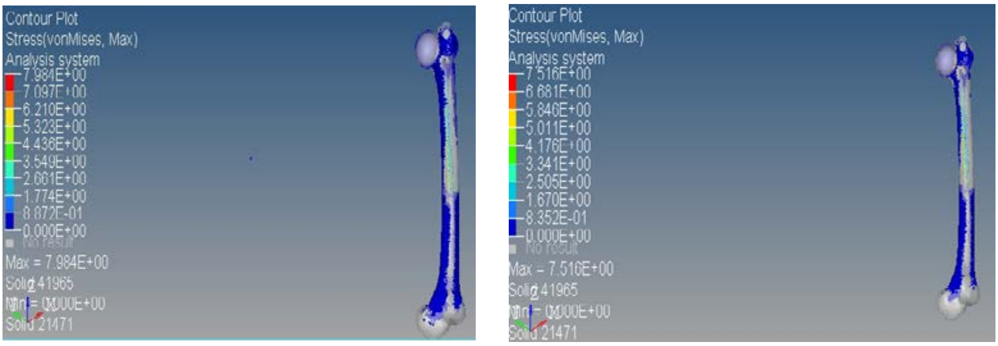

Figure 11. Stress Patterns of existing and modified intramedullary rod setup for 367.875 N load

## 5. RESULTS AND DISCUSSIONS

In order to obtain additional strength and stability, modified trapezoidal nail shape is used in the modified intramedullary rod setup. It also provides resistance to femoral head rotation. Potentially it improves patient mobility and recovery since the modified design is in par with the anatomy of the human femur bone. Analysis results of deformation and stress are given in Table 1 & Table 2, respectively.

Table 1. Analysis Results of Deformation

| Sl. No. | Load (N) | Deformation (µm) | | Reduction in Deformation (µm) | Percentage Improvement |
|---|---|---|---|---|---|
| | | Existing Design | Modified Design | | |
| 1 | 318.825 | 0.972 | 0.907 | 0.065 | 6.7 % |
| 2 | 343.350 | 1.050 | 0.920 | 0.13 | 12.4 % |
| 3 | 367.875 | 1.101 | 1.036 | 0.065 | 6.7 % |

Table 2. Analysis Results of Stress

| Sl. No. | Load (N) | Stress (MPa) | | Reduction in Stress (MPa) | Percentage Improvement |
|---|---|---|---|---|---|
| | | Existing Design | Modified Design | | |
| 1 | 318.825 | 7.053 | 6.576 | 0.477 | 6.8 % |
| 2 | 343.350 | 7.614 | 7.212 | 0.402 | 5.3 % |
| 3 | 367.875 | 7.984 | 7.516 | 0.468 | 5.9 % |

Comparison is done between existing and modified intramedullary rod setup with different load conditions. The stress and the deformation of modified design is lesser than the existing design. There is at least 5% improvement is obtained for any loading conditions. So, this shows that the modified design is better than the existing design.

## 6. CONCLUSIONS

i. Additional strength and stability is obtained with the help of modified trapezoidal cross section in intramedullary rod.
ii. Improved patient mobility post operation is obtained since the design is in par with the anatomy of the femur bone reducing the chances of bone grafting during operation.
iii. Active compression is achieved through a linear motion without rotation.

## CONFLICT OF INTEREST

The author confirms that there is no conflict of interest to declare for this publication.

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