

# Finite Element Analysis of Proximal Femur Nail for Subtrochanteric Fractured Femur

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## Abstract

The aim of the present work is to study the biomechanical behavior of the femur implant assembly during fixation of a simple transverse subtrochanteric fractured femur using a commonly known implant called Proximal Femur Nail (PFN). Finite element Analysis tool is used to study the bio-mechanical behavior of the femur and the implant assembly. The “standardized femur” is downloaded from repository of the Society of Bio-Mechanical Engineers and subsequently repaired to make it usable for this Finite Element Simulation. The modeling software Unigraphics and finite element simulation software ANSYS are used for the present study. A simple transverse subtrochanteric fracture located 30mm below the lesser trochanter is modeled using contact elements for this present study. A static linear finite element analysis is performed to study the intact femur. A non-linear contact analysis is performed to study the fractured femur with implant assembly. The implant is studied for deflection, stress and strains. The present work has considered the full femur and modeled with non-homogeneous material properties for the bone material. The displacement and principle stress on the proximal femur have been compared with the intact model. The contact results are used to estimate the condition of healing process at the fracture interface.

## Introduction

Finite Element analysis is a useful tool for the analysis of implants in fractures of femur. Such a study not only helps one to understand the relation between the form and function, but also be an important input for the surgeon during his work. In this present study, sub trochanteric fracture in traverse plane is considered for the analysis. The implant *Proximal Femur Nail* (PFN) was selected for evaluation and comparison with the intact femur. To simplify the experimental cross-validation of numerical studies, a CAD solid model of a synthetic human femur “standardized femur”, commonly used in experiments in vitro, was made available in the public domain from the International Society of Biomechanics Finite Element Mesh Repository (Marco Viceconti et al., 1996). A number of research papers have considered the bone material to be linear elastic, and isotropic for the purpose of simplicity in the analysis of the femur, though extensive study is going on in modelling of femur using orthotropic material properties (Dieter Christian Wirtz et al., 2003). The femur has been considered with two distinct material properties for cortical and trabecular bones (Cristofolini et al., 1996), as well as with finer divisions for material property variation (Wang et al., 1998). Also a full orthotropic finite element femur model has been developed (Dieter Christian Wirtz et al., 2003). Another variation of the model is the femur with two different material properties for cortical and cancellous bone (G.Cheung et al., 2004). It has been shown that material properties vary widely for head, neck, trochanteric and shaft region of the femur (K. Sitthiseripratip et al., 2003)

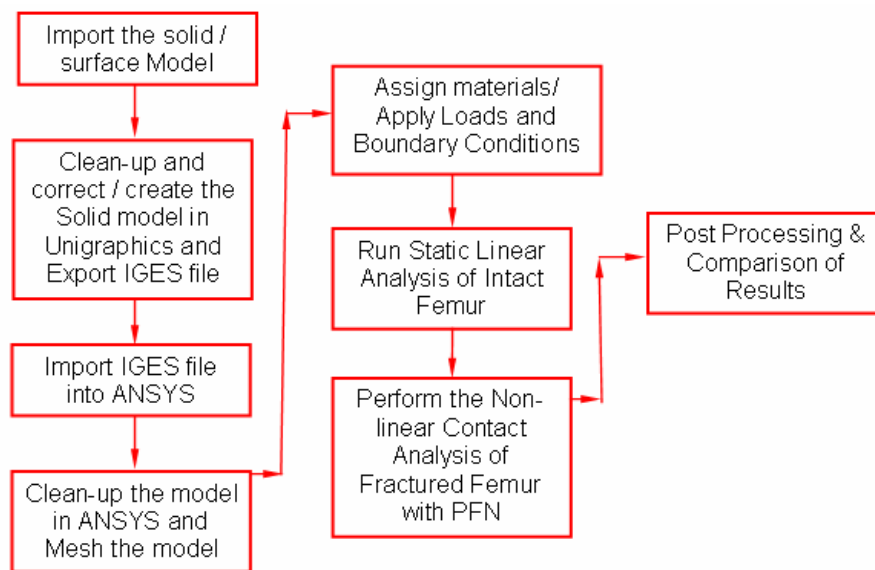
A number of research papers have discussed various loads acting on the human femur and some of them have simplified the complicated muscle loads into major forces acting on the femur. The effect of muscle forces on the femur has also been studied (Simoes et al., 2000). The hip joint and abductor-muscle forces acting on a femur during loading of a cemented total hip reconstruction is explained in the literature (Stolk et al., 2000). The study includes the effect of iliotibial tract (ITB) on proximal femur. K. Sitthiseripratip et al., (2003) in their FE study of trochanteric fracture fixation by a trochanteric gamma nail (TGN), considered only the abductor muscle force and joint reaction forces for one-legged stance loading

condition. The femoral model was fully fixed (zero displacement) at the distal end. The load condition consisted of a joint reaction force applied to the femoral head and an abductor muscle force applied to the greater trochanter. B.Seral et al., (2004) used a simple model for his finite element analysis study on trochanteric fractures of the hip with Gamma Nail and Proximal Femoral Nail. The goals of the present study are:

1. To study the bio mechanical behaviour of the intact femur.
2. To investigate the bio mechanical behaviour of the fractured femur with the PFN implant.
3. To report various stress, strain and displacements on the implant assembly.

## Procedure

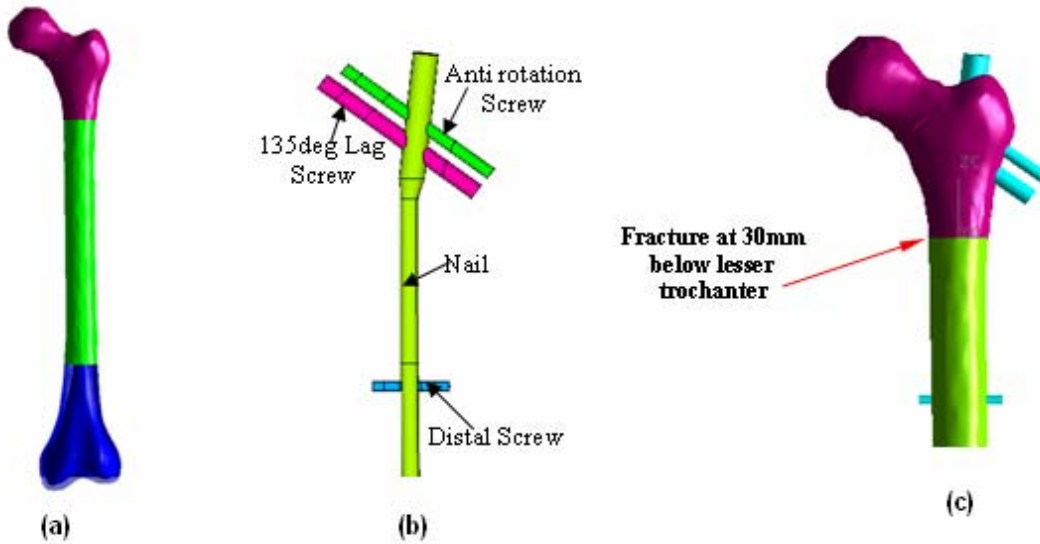
The typical analysis procedure for the femur analysis is shown in the figure 1. The procedure has been explained in the following sections of Solid Model, FE Model, Analysis and Results sections.



**Figure 1. Analysis Procedure Road Map**

### **Solid Model**

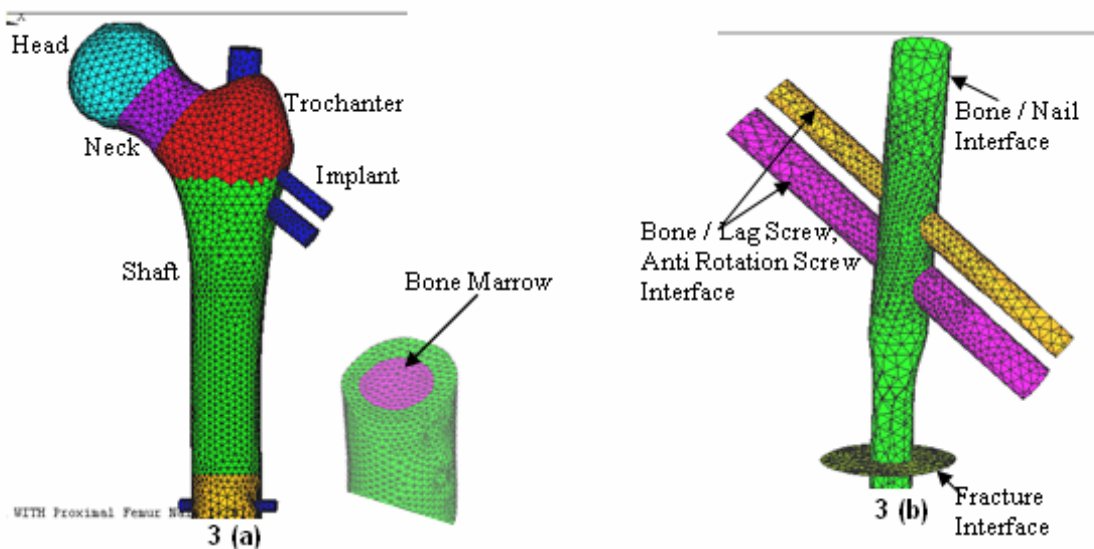
The 3D solid model of the femur used in this analysis was downloaded from the repository available in the website “[http://www.tecno.ior.it/VRLAB/researchers/repository/BEL\\_repository.html](http://www.tecno.ior.it/VRLAB/researchers/repository/BEL_repository.html)” called “standardized femur”, an IGES file made available in public domain (Vicecont et al., 1996). So far around 2000 engineers have downloaded this femur model for their biomechanical study and have been reported in many papers. The downloaded surface model (IGES file) had many missing surfaces which were very complex to recreate. This missing surfaces were re-modelled using the 3D solid modeling software Unigraphics and the solid model of the femur was created. While re-modelling, the femur model was made suitable for the finite element model preparation. An Implant model was created in Unigraphics software using actual implant obtained from the clinic. Boolean operations were performed to obtain the assembly condition of the femur and implant. The femur model is split according to the material properties assigned in various region. The solid model is shown in the figure 2. Minute detail like threads of the lag screw and threaded end of the distal screws are not modeled and simplified as cylindrical objects.



**Figure 2. Solid Model of Intact Femur (a) , Solid Model of the PFN (b) and Femur with PFN Implant (c)**

### ***Finite Element Models***

The solid model is discretized into 10 noded tetrahedral elements ( Solid 92). The finite element model of the femur with PFN implant is shown in the figure 3a. Different regions were introduced in the model as shown in the figure 3a., enabling the definition of different material properties. Contact conditions have been established using 6 noded surface to surface contact, target elements (contact 174, target 170), called as contact pairs. The different contact interfaces created are fracture surface interface, implant and Bone interface and lag screw and nail interface as shown in the figure 3b. For all the contact pairs, implant has been considered to be the target elements on which the contact elements (bone elements) cannot penetrate. The standard contact option was used for the entire simulation.



**Figure 3a. FE Model of Femur with PFN Implant**

**Figure 3b. Different Contact Interfaces of Fractured Femur and PFN Assembly**

## **Material Properties**

Linear elastic isotropic material properties were assigned to all materials involved in the model (K. Sitthiseripratip et al., 2003). Different material properties were attributed to different femoral regions, as shown in Figure 3a, namely, the cortical bone in the femoral shaft, trabecular bone in the femoral head, the femoral neck and the trochanteric region. Corresponding elastic constants are given in Table 1. Stainless steel material properties were assigned to the implants. Frictional coefficient of 0.20 is assigned to all the contact elements.

**Table 1. Material Properties assigned to femur and implants**

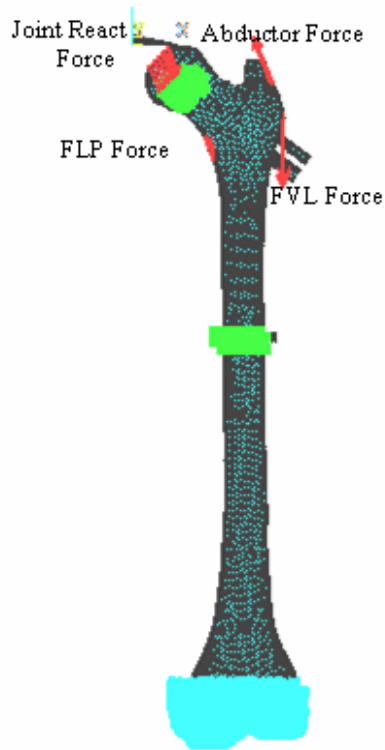
| Sl.No | Item        | Elastic Constant (E), MPa | Poission's Ratio |
|-------|-------------|---------------------------|------------------|
| 1     | Head        | 900                       | 0.29             |
| 2     | Neck        | 620                       | 0.29             |
| 3     | Shaft       | 17000 to 14000            | 0.29             |
| 4     | Bone Marrow | 100                       | 0.29             |
| 5     | Trochanter  | 260                       | 0.29             |
| 6     | Implants    | 2e5                       | 0.30             |

## **Load and Boundary conditions**

The distal end of the femur model, (condylar surface) was fully fixed (zero displacement). The various loads due to body weight and various muscles at proximal femur corresponding to (Simoes et al. ,2000) were considered for the analysis. The applied loads consist of joint reaction force, abductor force, Iliopsoas force and vastas lateral as shown in the table 2 and figure 4. The threaded end of the dynamic sliding screw and anti rotation screw was coupled with femoral head. The threaded connection of the distal screw was simulated using multipoint constraints between the screw outer surface and screw holes.

**Table 2. Various forces applied on the femur**

| Sl. No. | Type of Load              | Force, N |
|---------|---------------------------|----------|
| 1       | Joint Reaction force, JRF | 730      |
| 2       | Abductors, ABD            | 300      |
| 3       | Iliopsoas, FVL            | 188      |
| 4       | Vastas Laterals, FLP      | 292      |



**Figure 4. FE Model of Femur with PFN Implant- Loads and Boundary Conditions**

## **Analysis**

Two types of analyses were performed in this present work.

- 1) Static Linear Analysis of intact femur and
- 2) Non- Linear Contact analysis of fractured femur with PFN implant.

The analysis results are discussed in the following section.

## **Analysis Results & Discussion**

It is very important to know about the deflection of the intact femur and fractured femur with implant, so that we can study what amount of load has been shared by the implant. It is also very important to have the stability at fracture site so that bone fracture healing process is faster. The stability is achieved by two factors.

- 1) The controlled deflection of femur at fracture site.
- 2) The sufficient amount of surface contact area and contact pressure at fracture plane.

Once the stability is achieved, the sufficient amount of vascular supply is available at fracture site enabling the bone healing process faster.

Based on the analysis results, the deflection of intact and fractured femur were compared. The axial strain which is very important for the stability is compared with the intact femur to find out how effective the PFN implant is. The femur being brittle material, principal stress is plotted and reviewed. The implant

(PFN) being the ductile material, is reviewed for its von-Mises stress to find out the peak stresses on the implant.

### ***Deflection of the femur***

For the PFN implant configurations the overall deflection  $\sqrt{U_1^2 + U_2^2 + U_3^2}$  is found to be 4.08mm. It is closer to the deflection value of intact femur (4.2mm). Though the deflection in the anterior – posterior direction is very much lower, the lateral deflection ( $U_x$ ) is found to be higher (3.7mm) when compared to the intact femur (0.39mm). This indicates that the femur tends to slide on the lateral direction and the PFN implant could not hold the implant's stability in that direction.

A comparison of the deflections in each directions are shown in the figure 5. As can be seen from the figure, the overall deflections of the PFN femur is even lower than the original intact femur. But, their lateral deflections are higher.

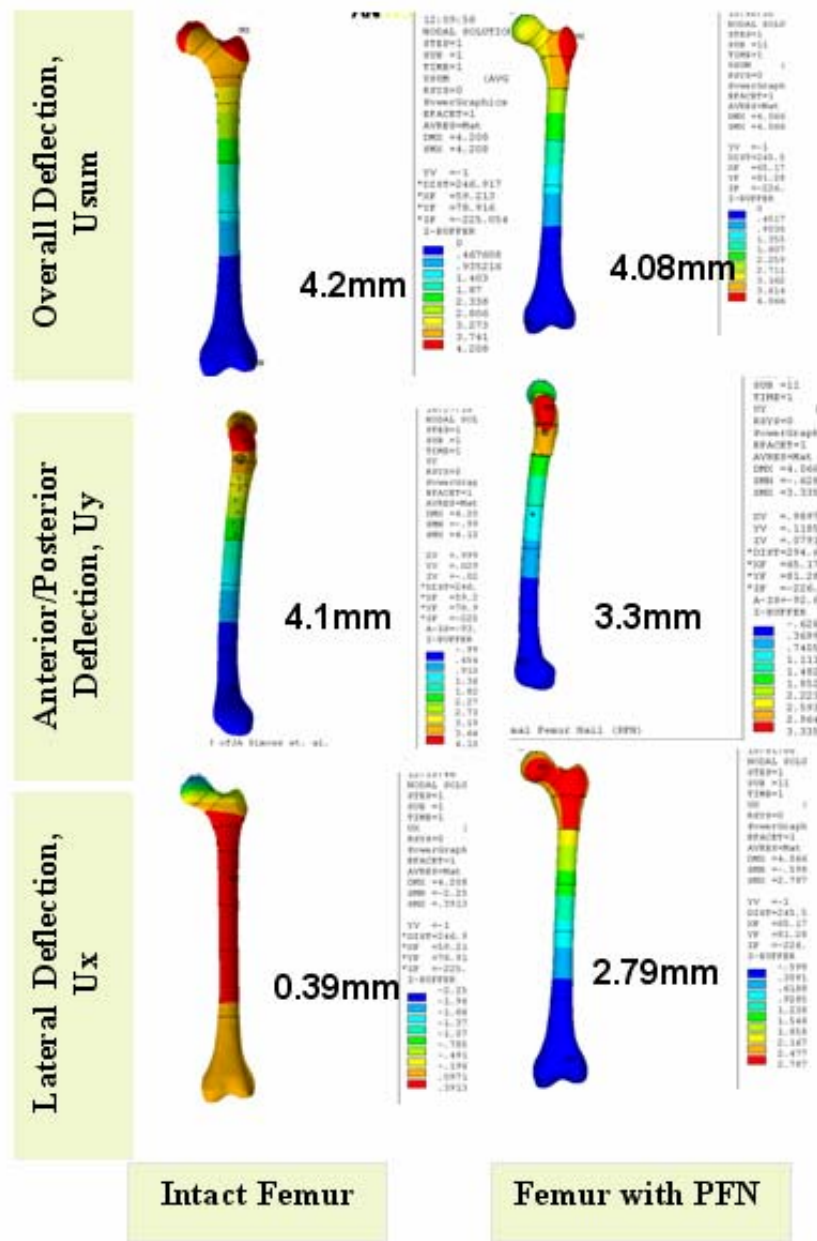


Figure 5. Deflection Comparison of Intact Femur and Fractured Femur with PFN implant

### Axial Strain Distribution

The distribution of axial strain along the femoral axis is shown in the figure 6. The axial strain of implanted femur is compared with that of intact femur. This will enable us to study the amount of load transfer take place in femur and implants. Also, the effectiveness of implant at fracture site can also be studied. Two important observations can be made from these figures. Firstly, the mechanics of deformation of the intact femur, while that of the PFN implanted femur is different and seems to bend in a different plane than the intact femur. This has resulted in a more complex strain distribution. The above observation can be deduced from the similarity of distribution of the strain along the length of the femur. It is seen that PFN implant has resulted in reducing the strain in the medial side (compressive) and it has very no effect on the lateral side of the proximal femur. It can be shown that, the medial and lateral strains are distributed

symmetrically for PFN implanted femur using the axial strain plot. ie., The PFN implant dominates in the motion control of the femur and implant assembly.

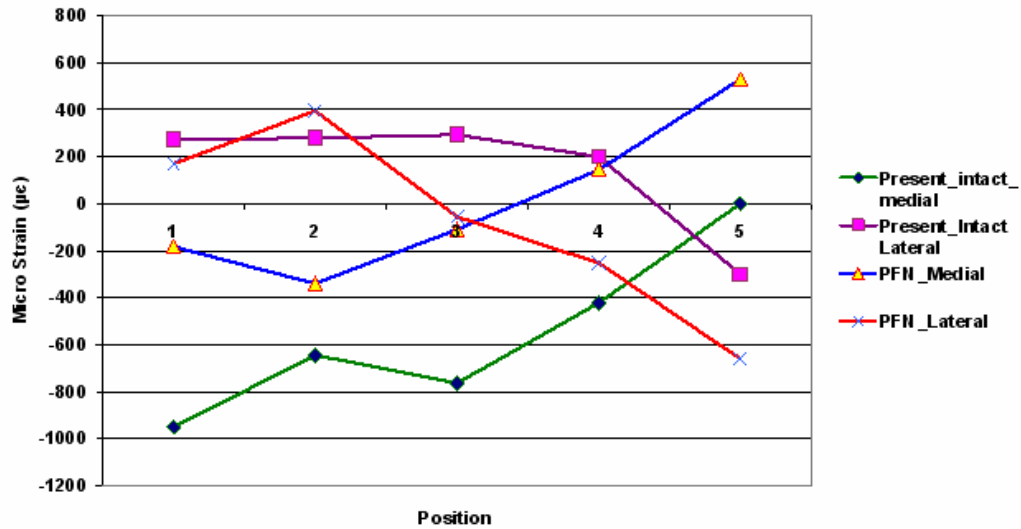


Figure 6. Distribution of Axial Strain Variation along the femoral Axis - Comparison

### Principal Stress Distribution

The comparison of maximum and minimum principal stresses for all three implanted femur are shown in figure 7 and figure 8. The aim of implant is to reduce the internal stresses of the femur in terms of clinical requirements for the faster healing. It is seen that the minimum principal stress is higher and very much localized at fracture site when compared to the intact femur. The lower surface area of contact causes the stress near the fracture site to be more than the intact femur in that location. The maximum principal stress is found to be the same as intact femur.

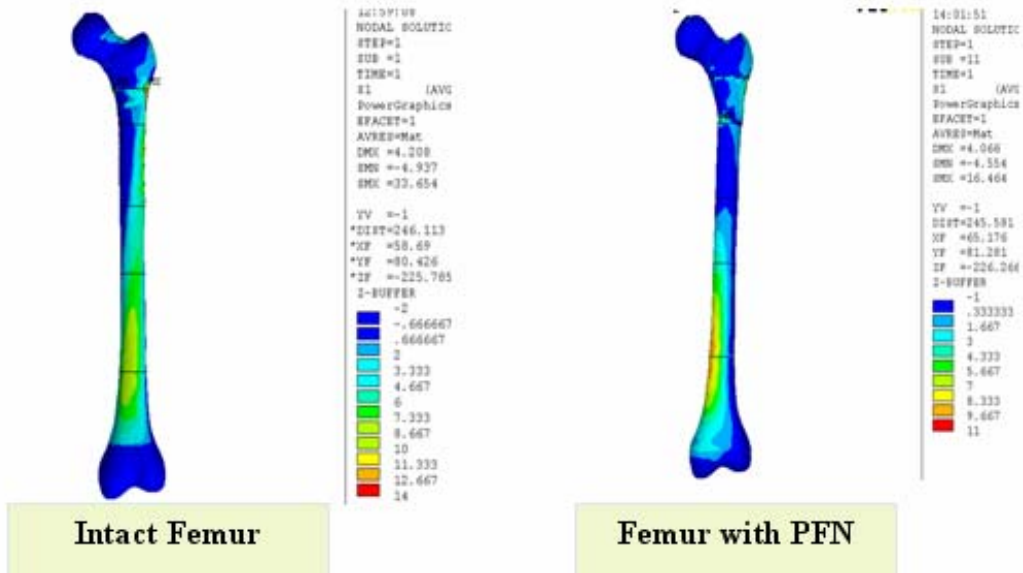


Figure 7. Maximum Principal Stress on Intact femur and Femur with PFN Implant

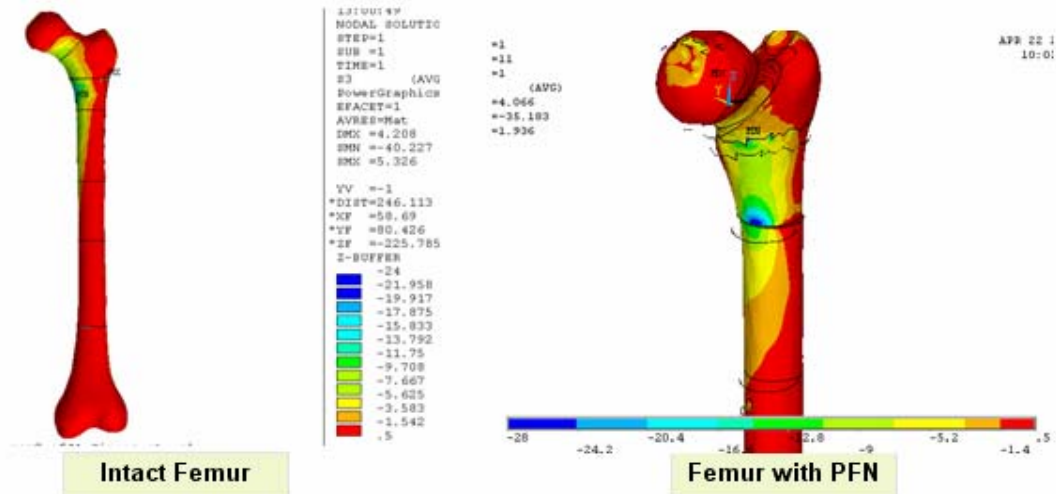


Figure 8. Minimum Principal Stress on Intact femur and Femur with PFN Implant

### Stress Distribution on the Implants

von Mises stress induced on the components of the PFN implant are shown in the figure 9. It is observed that PFN implant experiences high localized von Mises stress around lag screw hole (390 MPa). This high stress is observed only near the 135 degree hole location. This may be due to the contact between the hole and the lag screw. Since the value of this high stress is beyond the yield value of the stainless steel material, the design of the PFN should facilitate some kind of stress relief. The other locations of the PFN assembly experiences very low stress only.

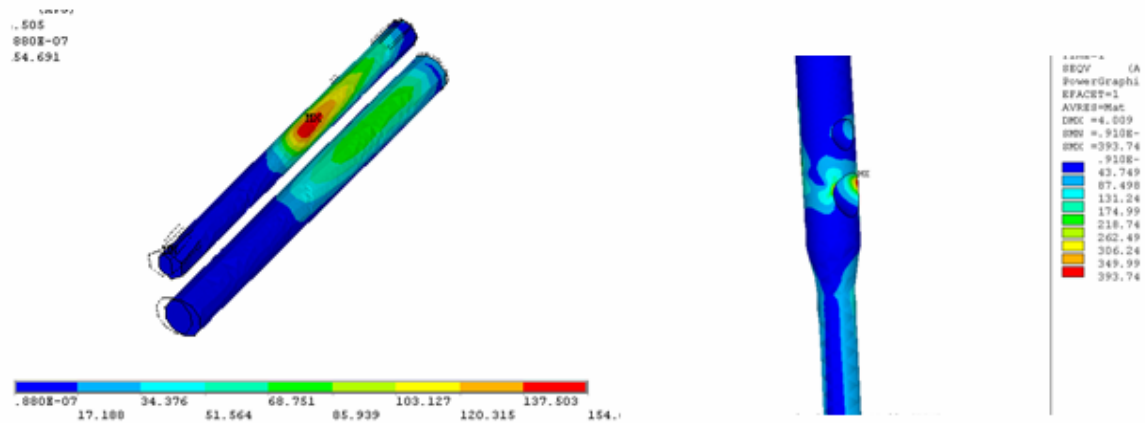


Figure 9. von-Mises Stress on the PFN Implant

### Contact Status and Stress on the Fracture surface

Bone healing process depends on the stability after the fracture. The stability is achieved by internal fixation using the implants. One of the measures to verify the stability is to check the bone contact surface area at fracture interface surface. The contact status and contact pressure at fracture plane are compared in figure 10. It is noticed that PFN implanted femur has a very low contact area and high localized contact stress which is not a encouraged result for the healing.

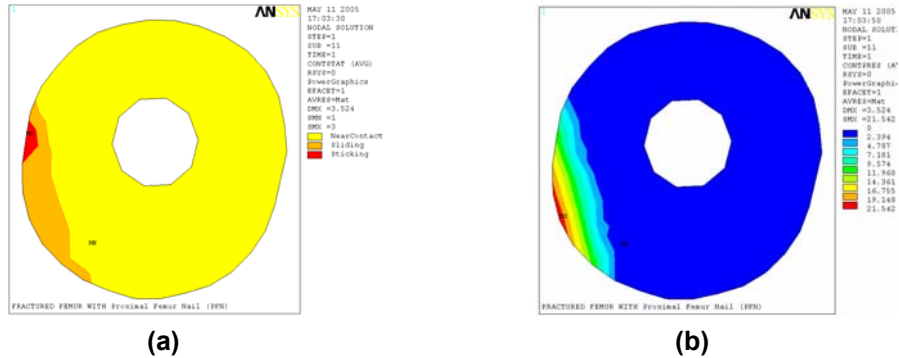


Figure 10. Contact Status (a) and Contact Pressure (b) at Fracture Interface

## Conclusion

The study shows that PFN implanted femur results in lower stresses on the femur. But, while comparing the deflection pattern, the PFN allows the femur to deflect more in the lateral direction ( $U_x$ ). This may cause the top (proximal) femur above the fracture plane to slip and healing process would take more time. For the faster healing of fractures, the contact surface area should be adequately stressed. This depends upon the contact surface area and the pressure value on the contact surface. The results show PFN has very little contact area.

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