

Modelling and analysis of internal fixation devices for distal femoral bone fractures

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ABSTRACT

This work focused on to study the mechanical behavior of internal fixation devices for femur bone fractures. The bio-CAD model of intact femur bone model is developed using image-based techniques, and two conceptual model (Model-1 & Model-2) of internal fixation devices are developed using Pro/E software. The finite element analysis was carried out to understand stress distribution around the screw holes of the conceptual design of internal fixation devices. Fracture due to misalignment and unstable of the distal femur bone treated by operative incision process using various internal fixations devices like intramedullary nails, plates, and wires etc., the internal fixation devices are subjected with aseptic loosening and stress shielding due to mismatching of elastic modulus between bone and fixation devices. In order to understand stress distribution and stiffness of fixation devices finite element analysis was carried out using ANSYS. In this work, observed that order of screw fixations influences a significant amount of stiffness and stress value. Further, states that, based on the stiffness and stress value of the intact model, conceptual design model-1 has stiffer than model-2.

KEY WORDS: Bio-CAD, fracture, finite element analysis and conceptual model.

1. INTRODUCTION

In human anatomy, femur bone is a long and load bearing members, which extend from the hip joint to knee joint. The femur bone subjected to multiple forces such as compression, bending and torsion. Since bone is a heterogeneous and complex structure, it has mechanical properties such as stiffness, strength, stress, strain and Poisson's ratio, etc., similar to other engineering materials. Usually, the distal femoral fracture will occur when subjected to a sudden load. The Internal fixation of distal femoral fractures has accepted as non-operative treatments. However, the selection of implants devices used as internal fixation devices are still to improve. The anatomical structure of femur bone is shown fig.1.

The literature states, the fatigue fracture of a retrograde intramedullary nails with multiple-hole will be failed above 100,000 cycles loading because high tensile stress developed around the unused nail hole near the fracture site (Shih-Hao Chen, 2008). To our knowledge no work has done, regarding the biomechanical performance of femur-nail fixation with screw position configurations. The objective of this study to perform finite element analysis of newly designed conceptual internal fixation devices with intact distal fractured femur bone model and understand screws fixing position configuration.

Femur bone fractures: The femur fractures based on the force that causes to break. It is classified depends on:

- The location of the fracture of femoral diaphysis [proximal, mid and distal diaphysis]
- The pattern of the fracture for example, cross-wise, length-wise, or in the middle as shown in fig.2.

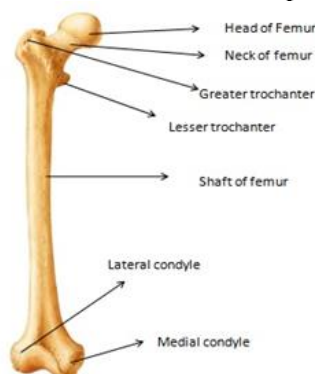


Figure.1. Femur bone model (Courtesy: Pearson Benjamin Cumming @2009)

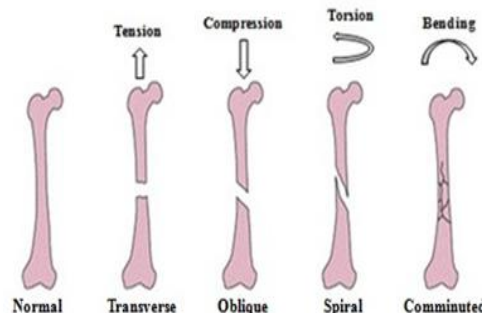


Figure.2. Different Types of fracture

Source for femur fractures: The femoral bone fractures will occur various possible sources such as

- The force from the bottom, due jumping from a certain height as standing positions may cause a femoral shaft fracture
- Aging person who has weaker bones also due to osteoporosis or bone arthritis
- Road accident/ trauma, it is a common cause, which is increases in our country day-by day.

Symptoms of femur fractures: The following symptoms usually observed in distal femoral fracture

- A femoral shaft fracture usually causes immediate, severe pain.
- Unable to carry own body weight, it may look deformed and shorter than other leg and no longer straight.
- Progressive muscle and joint weakness and pain

Treatments for femur fractures: In general, the treatments for femur bone fracture is surgical and non-surgical. The surgical procedure is done with fixation devices either external or internal fixation devices. The nonsurgical treatment, which is unusual for femoral shaft fractures most of the femoral shaft fractures require surgery to heal. But for a child sometimes treated with a cast. The aim of internal fixation is to achieve proper functioning of the injured bone and rapid rehabilitation of the patient. The most of the internal fixation implants are made up of stainless steel. Plates and Intramedullary nails or rods used for in operative incision. The plates used for both rigid and flexible fracture fixations. The majority of these plates are made up of stainless steel or titanium.

2. EXPERIMENTAL METHODS

Three - Dimensional (3D) Model of distal femoral bone was generated with medical images (CT images) using reverse engineering techniques. The Computer Tomography (CT) images of distal femoral are segmented with appropriate threshold value using Mimics software (The Materialise, Group, Leuven, Belgium) and 3D reconstructed model saved as STL (Steriolithography) file format. These STL was imported in to Geomagic software, in which converted as NURBS surface model. The finite element model generated with finer meshing size of NURBS model using Hypermesh software and saved as *.cdb file.

In general, Bio-CAD modeling processes are involved following three stage (1) non-invasive image acquisition (2) three-dimensional NURBS model generation (3) Bio-CAD model. The details steps involved are shown in fig.3.

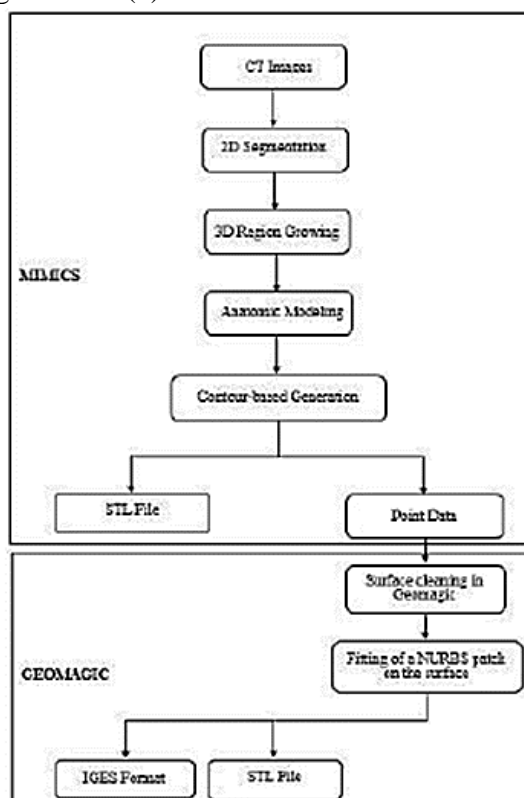


Figure.3. (A) Steps involved to conversion of CT images to bio-CAD model

In this study, the CT image of 52 years old human cadaver left femur bone was used to generate an intact femoral bone model. The stem implants are created using CAD software's (Unigraphics and Pro/E). The finite element analysis work was carried out under static loading and boundary conditions using ANSYS using following material properties.

Table.1. Material properties used in the finite element models (Shih-Hao Chen, 2008)

Material	Young's modulus (Gpa)	Poisson's ratio
Cortical bone	10	0.3
Titanium	105	0.29
Screws and Nails		
Polyurethane Resin	3	0.25

The purpose of the present quasi-static analysis, a compression load of 1000N applied at femoral head and center of the femoral condyles.

Finite element modeling:

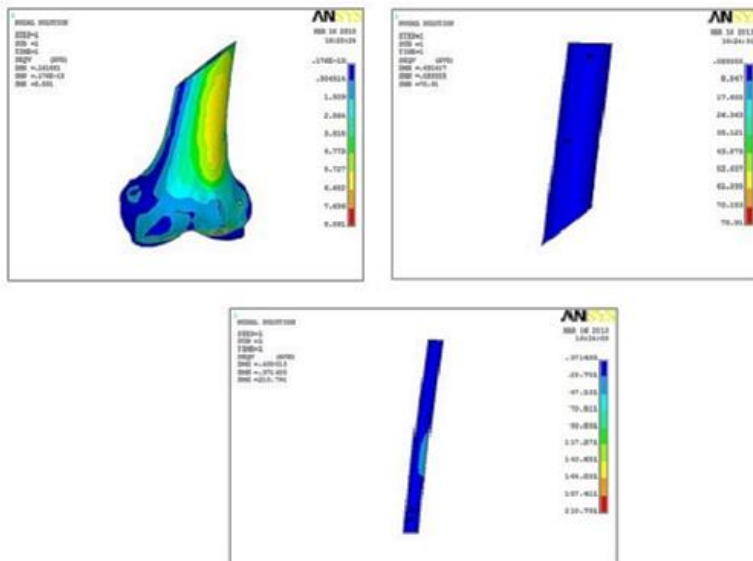


Figure.3.(B)Finite Element Analysis of distal femur and fixation devices

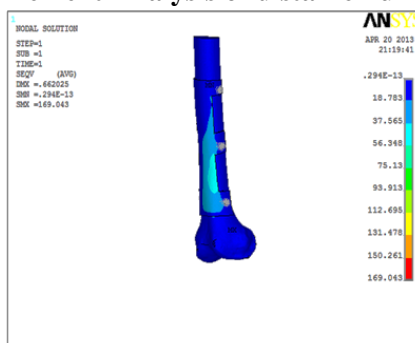


Figure.3.(C)Finite element model with fixation displacement using ANSYS

3. RESULTS

The decreasing of stress distribution will be lead to avoiding the risk fracture of the bone. In this work, finite element analysis was carried out with oblique fractured distal femoral bone using two different types of implants. The stiffness value obtained from conceptual model-1 is 83 %, which 5 % higher than literature value (Shih-Hao Chen, 2008). The stress concentration of intact model is 279.79N/mm². The conceptual model-1 and model-2 is 210.79 N/mm² and 169.04 N/mm² respectively. There is 15% of stress concentration difference between conceptual model-1 and conceptual model-2.

Table.2. Deformation – stiffness and stress obtained from ANSYS

Description models	FEA Values		
	Deformation (mm)	Stiffness (N/mm)	Stress (N/mm ²)
Intact Model	0.524	1905	279.79
Conceptual Model-1	0.631	1584	210.79
Conceptual Model-2	0.662	1511	169.04

The order of screw fixation improves the significant amount of stiffness for distal fractured femur bone.

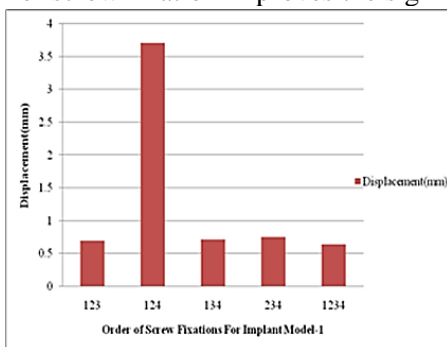


Figure.4. Displacement Vs Order of screw fixation – Model-1

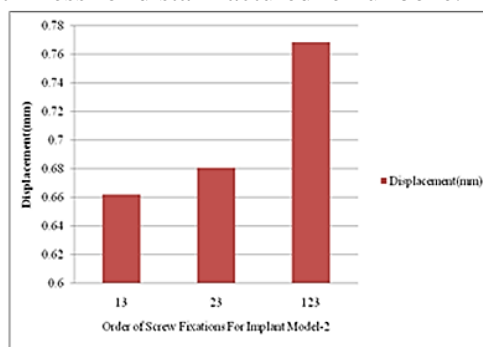


Figure.5. Displacement Vs Order of screw fixation for Model -2

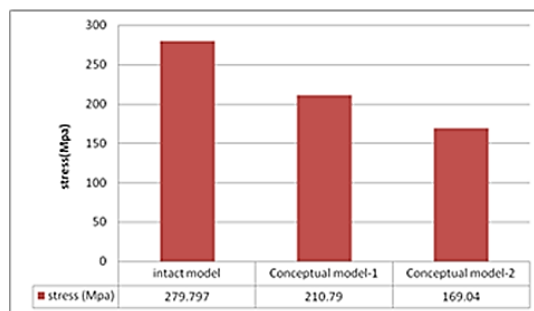


Figure.6. Stress distribution in the models

The conceptual model-1 has verified the stiffness by changing the order of screw fixations like 123,124,134,234 and 1234 as shown below fig. 7. The conceptual model-2 was verified the stiffness by changing the of order of screw fixations like 13, 23 and 123 as shown in fig.8

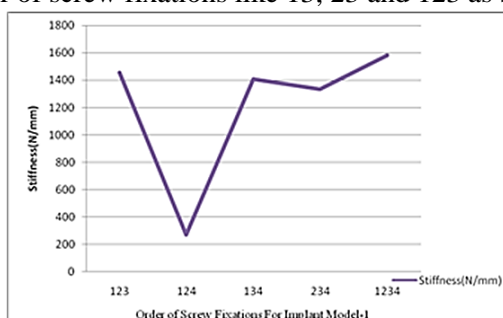


Figure.7. Stiffness variation by changing order of screw fixation for Model-1

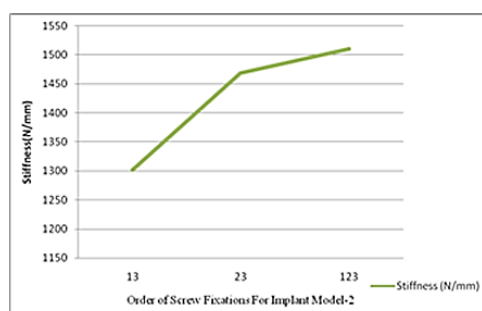


Figure.8. Stiffness variation by changing order of screw fixation for Model-2

The stiffness changes in conceptual model-1 and model -2 are by changing the order of screw fixations as shown in Figures 7 & 8. The stiffness changes due to change in length of screw fixation.

4. CONCLUSION

In this work, we understand the intact femur bone model and conceptual implant models are most suitable for joining of the fracture in distal femur bone. The results indicate, the stiffness of conceptual model-1 is 83% of the intact model when the screws were fully fixed, and stiffness of the conceptual model-2 (shield type plate) is 79%. The changes in screw fixations will not significance stress distributions of conceptual models but consistently near to the intact femur bone model. The stress distributions of conceptual model-1 are 15% more than that of conceptual model-2. The stiffness of conceptual model-1 was improved by 5% more than that of conceptual model-2. The conceptual implant model-1 may be preferable for the fractured femur bone.

Further scope of this study was to find out the stress distributions of internal fixations for different other types like transverse, spiral, comminuted fractures in femur bone. Optimizing the implant models may be taken for clinical considerations.

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