Finite Element Analysis of a Sliding Hip Screw

[1]Daniel Gilroy, [1]Phil Riches and [2]Marcus Wheel
[1]Department of Biomedical Engineering, University of Strathclyde, UK
[2]Department of Mechanical Engineering, University of Strathclyde, UK; email: Daniel.gilroy@strath.ac.uk

SUMMARY

A sliding hip screw (SHS) is an orthopaedic device that is used in the treatment of extracapsular proximal femoral fractures. This paper presents the development of a finite element (FE) model of an SHS implanted in a fractured femur.

INTRODUCTION

As the average life expectancy of the population has increased, the number of incidents of hip fracture has also increased significantly, with the number of fractures expected to reach 4.5 million worldwide by 2050 [1]. The SHS is a simple effective device that is used in the treatment of proximal femoral fractures. The design of the SHS has not changed significantly since its development in the 1950s and relatively little biomechanical analysis has been carried out to evaluate the mechanical performance of these devices.

The modelling of an implant in bone is a complex problem; many assumptions must be made about the material behaviour of the bone, the interaction between the bone and the implant at their interface and the loading and boundary constraints which are applied. One of the most complex areas of any model is the interaction between the bone fragments at the fracture site. The conditions at the fracture site vary throughout the healing process and experimental validation of the fracture model is very difficult.

Previous 3D models of a SHS implanted in a fractured femur have involved unvalidated assumptions about material properties and contact conditions. Studies that have attempted to model the callus formation between the bone fragments [2,3] estimated the thickness and material properties of the callus layer without evidence. Some studies have attempted to measure the material properties of the tissue that forms between fragments [4,5] however these papers focus on the healing of fractures in the diaphysis of long bones which may differ from the healing of fractures at the epiphysis.

The aim of this study was to produce a 3D FE model of an SHS implanted in a fractured femur, which could be easily validated through planned mechanical testing. Unlike previously developed models this model analyse fracture pre-callous formation. The purpose of this model would be to compare the mechanical performance of SHS devices of various different geometries, looking at the stress and strain in both the implant and the bone as well as investigating the relative motion between fragments at the fracture surface. Micromotion at the fracture surface is fundamental to the stimulation of secondary bone healing and may therefore be a useful measurement in the comparison of SHS devices.

METHODS

A 3D model of the device implanted in bone was created using the 3D modeling package Autodesk Inventor Pro, Autodesk, California, USA. The 3D model was imported into ABAQUS (Dassault Systems, Vlizy-Villacoublay, France). A section view of the model can be seen in figure 1. As the aim of this study was to produce a 3D FE model that could be validated to prove its accuracy, it was decided that the fracture would be modeled as an idealised fracture in the trochanteric region of the femur, with the fracture surface of the fragments being flat and with no intermediate layer between them. This would allow the analysis to be repeated in a mechanical test.

Figure 1: Section view of model.

The model was meshed with 252888 first order tetrahedral elements. Linear elastic material properties were used to represent bone, for cortical bone E=16GPa and for cancellous bone 137MPa, a Poisson's ratio of 0.3 was used for both. These values are the material properties of the 4th generation composite bones produced by Sawbones, Vashon, Washington, USA. Mechanical testing will be carried out to validate this model using both cadaveric femurs and the sawbones composite femurs. This will allow the model to be validated as well as evaluating the performance of the sawbones against human femurs.

Threaded connections were simplified by modeling the screws as cylinders; a tie constraint was used to connect the screws to the holes. It is well established that, providing it is placed in the correct position, the neck screw will not cut out of the bone [6]. It was therefore deemed unnecessary to model this connection in detail. Several contact pairs were created, these being "Screw-Barrel" between the neck screw and the barrel of the plate, "Plate-Shaft" between the plate and the shaft of the femur, "Fracture" between the head and shaft of the femur and "Plate-Screw" between each of the shaft screws and the plate. Frictionless contact was used for all contact pairs except the fracture. As the contact conditions at the fracture site were unknown and presumed critical to the outcome of the analyses, it was decided that several analyses would be run with different contact conditions. The results from the mechanical testing, that will be carried out to validate this model, could then be compared to the results from analyses using several different contact conditions, allowing the most accurate condition to be identified. Five different contact conditions were analysed, frictionless, penalty friction with frictional coefficients of 0.1, 0.5 and 1, and "healed" for which the two fracture surfaces were tied.

The model was fully fixed in all directions at its mid-diaphyseal cross section. A displacement controlled test was carried out by applying a -2mm displacement in the z-direction to a single node at the top of the femoral head. The applied displacement was ramped linearly over 1000 time steps. Automatic time stepping was used with an initial step size of 1, a minimum of 1e-10 and a maximum of 10. The model was solved using the Abaqus standard solver.

RESULTS AND DISCUSSION

The force-displacement curves for the model can be seen in figure 2. It can be seen that after a small non-linear section over the first 0.1mm of displacement the curves become linear. The model with the frictionless contact condition has the lowest stiffness. The stiffness of the model increases with an increase in the frictional coefficient at the fracture site. The "healed" condition is the stiffest as expected.
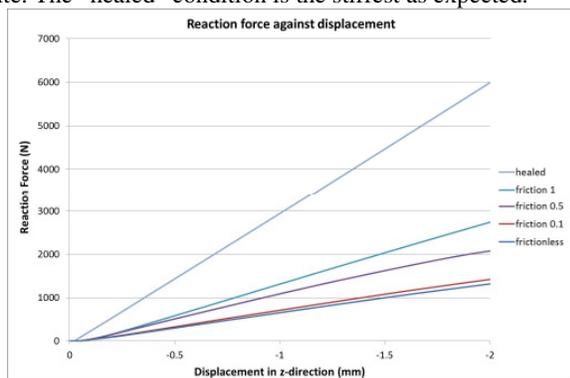
Figure 2: Reaction force-Displacement curve for model.

Figure 3 shows the z strain in the cortical bone of the femoral shaft from the analysis with frictionless contact. During mechanical testing strain gauges will be placed on the femoral shaft to allow the results from this model to be validated against experimental data. Figure 4 shows the separation at the fracture contact pair for both the frictionless and friction μ=1 conditions. For the same

applied displacement the fracture separates more with the friction condition than with the frictionless. The grey elements are those where the nodes have a larger value for contact opening than Abaqus records. Thus this model is able to discriminate relative displacement between the bone fragments which will allow investigation of micromotion in future analyses.
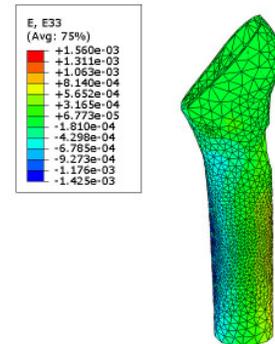
Figure 3: Z strain in cortical bone from frictionless analyses.
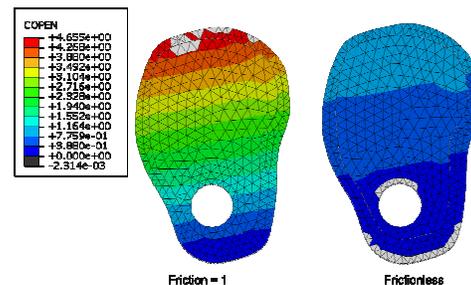
Figure 4: Separation at fracture contact pair in mm.

CONCLUSIONS

The model produced for this study includes complex femur geometry, with both cancellous and cortical bone, and functions well with several different contact conditions. This work has highlighted the importance of bone-bone friction in the modeling of the fracture pre-callous formation. Mechanical testing will be carried out to validate this model and identify the correct frictional condition for use in further analyses. The fully validated model will allow the mechanical performance of different SHSs to be analysed and compared.

REFERENCES

1. Gullberg B, et al., *Osteoporosis International*. **75**:407-413, 1997.
2. Sim E, et al., *Injury*. **26**:445-449, 1995.
3. Rooppakhun S, et al. *World Accademy of Science, Engineering and Technology*.**45**:662-665, 2010.
4. Markel MD, et al., *Journal of Orthopaedic Research*. **8**:843-850, 1990.
5. Leong PL et al., *Acta Bio-materialia*. **4**:1569-1575, 2008
6. Baumgaertner MR, et al., *The Journal of Bone and Joint Surgery (American edition)*, **77**:1058-1064, 199