Biomechanical Effect of Nail Length to Thai Femoral Shaft Fracture

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Abstract

The intramedullary (IM) nail has been most frequently used to stabilize the surgical treatment of dia- and metaphyseal fracture. This study was aimed to use the IM nail to fix the femoral shaft fracture and conduct finite element analysis to determine the stress distribution on the IM nail and strain distribution on the fracture gap under walking condition. The IM nail was varied in 3 different lengths; 360, 380, and 400 mm from the proximal part. The result showed that the maximum von Mises stress on the IM nail was 480, 400, and 350 MPa. respectively. The longest nail showed the least stress distribution comparing to the others.

Keywords: Femoral shaft fracture, IM Nail, Biomechanics.

1. Introduction

Intramedullary (IM) nails are usually used in the treatment of fracture of the femur. A wide range of nail designs and screw configurations used to fix the nail to the bone exist. IM nails are implants placed within the intramedullary canal of a bone to stabilize long bone fracture. They also maintain alignment of the fracture ends during the healing process. It is a load sharing device which permits load bearing across the fracture site. IM nails are most often made of either stainless steel or titanium alloy, and are generally used to secure the bone via of screw inserted through the implant at either end. AISI 316L stainless steel is widely used as biomaterials [1] due to its unique property of good corrosion resistance and biocompatibility.

The objective of this study was to try to predict the length of IM nail required in medullary canal of femoral shaft fracture from proximal part using finite element analysis in a Thai femoral bone.

2. Materials and methods

2.1 Thai femoral bone

The bone model was an average Thai femoral bone from 108 Thai cadaveric femur retrieved from Thai cadaveric femora database. The donor ages ranged between 22 and 83 years (average: 48.5) at the time of death. The geometry of Thai proximal was collected by CT scanner (Tomoscan AV). The result optimizing inner and outer contours were then exported into the IGES format [2].

2.2 Intramedullary nail

The CAD model was created from SolidWorks software with commercial specification. Universal femoral nail was made from stainless steel (AISI 316L). It has 1.2 mm. wall thickness, cloverleaf cross section, and 1500 mm. radius of curvature [3]. Universal femoral nail used in this study has a diameter of 13 mm. with 3 different sizes of length (360, 380, 400 mm. respectively) in manufacturing.

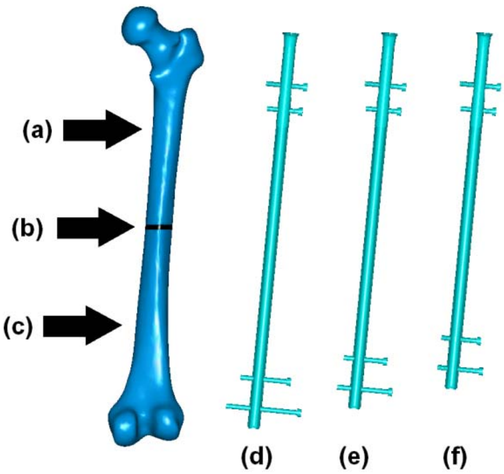


Fig. 1 Thai femur model, (a) Proximal femur. (b) Fracture gap, (c) Distal femur and IM nail length (d) 400 mm., (e) 380 mm. and (f) 360 mm.

The type of fracture is transverse shear at mid-third region. Proximal part use 2 screws to fix the bone and intramedullary nail, 1 screw at the dynamic locking hole and 1 screw at the static locking hole. Distal Part used 2 screws to fix bone and intramedullary nail at static locking hole. The fracture gap size in the model was at 5 mm.

2.3 Virtual insertion

The virtual insertion [4] of intramedullary nail to Thai femur are summarized as follow:

- The first step was to evaluate femoral shaft axis by using the center of canal be the center point of axis.
- The second step was to evaluate intramedullary nail axis.
- The third step was to insert intramedullary nail to intramedullary canal by aligning best position of intramedullary nail axis to femoral shaft axis.
- The final step was to rotate and install intramedullary nail along the femoral shaft axis in the right position.

Fig.2 Position of implant when inserted into the 3D femoral model.

Four-node tetrahedral elements were used to build up the mesh of the femur-implants and it were consisted of 134,050 nodes and 547,493 elements.

All models were assumed to be linear elastic, an isotropic and homogeneous material. The materials properties were shown in Table.1

Table.1 Mechanical properties of the materials used [5, 6].

Material	Young's modulus (MPa)	Poisson's ratio
Stainless steel	200,000	0.3
Cortical	14,000	0.3
Cancellous	600	0.2
Connective tissue	3	0.4

For calculation, loading conditions has to be fixed in order to set a boundary condition in finite element model. The musculoskeletal loading position and finite element model of femur when insert implants was show in Fig.3 and it condition was calculated from complete cycle of walking activities as shown in table 2.

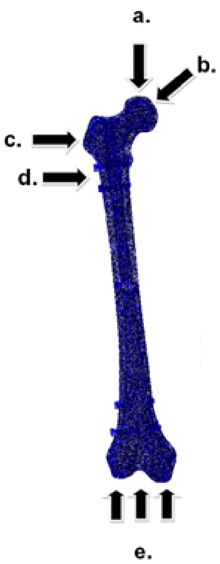


Fig.3 Finite element model of femur when inserted implants with musculoskeletal loading position.

Table.2 Musculoskeletal loading conditions [7].

Force	x-axis	y-axis	z-axis
a. Body weight	0	0	-836
b. Hip contact	-54.0	-32.8	-229.2
b. Intersegmental resultant	-8.1	-12.8	-.78.2
c. Abductor	58.0	4.3	86.5
c.Tensor fascia latae, proximal part	7.2	11.6	13.2
c. Tensor fascia latae, distal part	-0.5	-0.7	-19.0
d. Vastus lateralis	-0.9	18.5	-92.9
e. Fix displacement	0	0	0

3. Result

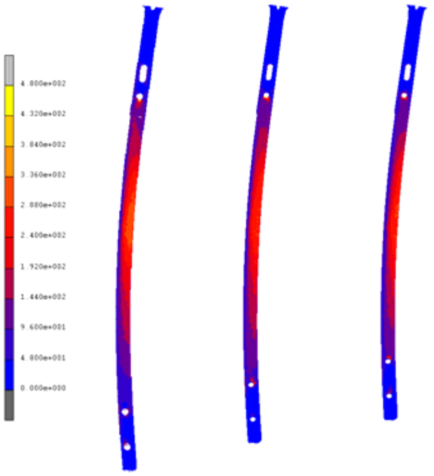
From the study, maximum von Mises stress on the implant and total strain in the gap were calculated by finite element analysis. Maximum von Mises stress on implants increased when nail length was shortened. The maximum von Mises stress in screw occurred in proximal static locking screw.

The highest maximum von Mises stress that occured on intramedullary nail, was on model 3 (nail length 360 mm.) and the lowest maximum von Mises stress occured in model 1 (nail length 400 mm.) as shown in Table 3.

Table. 3 Maximum von Mises stress in intramedullary nail.

Model	Nail length (mm.)	Maximum von Mises stress (MPa.)
1	400	350
2	380	400
3	360	480

The stress distribution on IM nail is shown in Fig 4.



(a) (b) (c)

Fig.4 Maximum von Mises stress on IM nail of (a) model 1, (b) model 2 and (c) model 3.

The maximum total strain in fracture gap was shown in table 4 and strain distribution was shown in Fig 5.

Table. 4 Maximum total strain in fracture gap.

Model	Total strain (με)
1	160,000
2	120,000
3	110,000

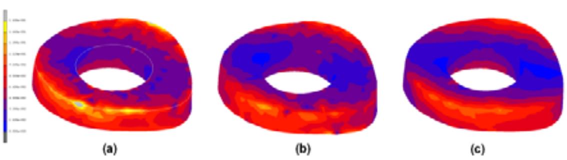


Fig.5 Strain distribution in fracture gap of (a) model 1, (b) model 2 and (c) model 3.

Maximum von Mises stress on screw occurred at proximal static locking hole in model 1. The lowest maximum von Mises stress occured in model 3 as shown in table 5.

Table. 5 Maximum von Mises stress in proximal static locking screw

Model	Maximum Von Mises stress (MPa.)
1	1050
2	750
3	500

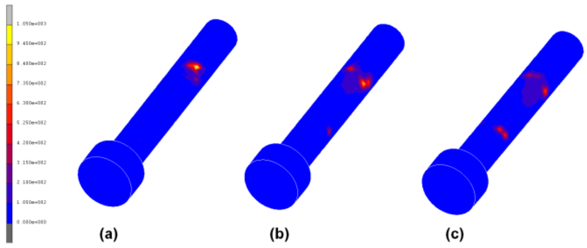


Fig.6 Stress distribution on proximal static locking screw of (a) model 1, (b) model 2 and (c) model 3.

4. Discussion

From, this study the result showed that the highest maximum von Mises stress appeared in the shortest IM nail that has the yield strength of 880 MPa (35% cold working) [8] and decreased when the length of the nail was increased. Maximum von Mises stress that occured in IM nail showed a capability of the nail in terms of sharing musculoskeletal loading and body weight from the bone. Though, the strain distribution on the fracture gap showed that the patient should not bear the full load on the fractured bone during the healing process. The strain must be in ranged of 4,000 microstrain for a good remodeling bone process. The longest Intramedullary nail can distribute stress better than the others because its contact area with the medullary canal is much larger than the others.

5. Conclusion

The surgeon should use the long nail that has the distal part away from the fracture gap for a good mechanical performance and the patient should not bear the full load during the healing process.

6. Acknowledgement

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7. References

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