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Biomechanical Study of Thai Femoral Bone Fracture with Gamma 3 Long Nail: Finite Element Analysis

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Abstract

This study was aimed to evaluate the mechanical performance of Gamma 3 Long Nail in Thai femoral bone. A Three-dimensional CAD model of the nail was created from Computed Tomography (CT) scan, and then the nail was inserted in to the bone, by Virtual Simulation, into the intramedullary canal. Then the geometric mismatch between the nail and intramedullary canal were measured. Finally, the mesh model of the bone and the devices was created for finite elements analysis. The fracture zone was on the Mid-third region of femoral shaft. The strain on the femur and the stress distributed on the screw and nails were observed under walking conditions.

***Keywords**:* Femur; Gamma 3 Long Nail; Healing; Stress distribution; Strain.

1. Introduction

The Gamma 3 Long Nail is the third generation of intramedullary short and long Gamma fixation nails [1]. The nail was designed to minimalize the surgery process and reduce the operating time. Therefore, blood loss and sepsis would be dramatically using the new technique.

The parameters of nail were based on Caucasian standard size. Its geometric mismatch was caused between the implant and the femoral shaft on the Thai femoral [2]. It could be modified by reaming the medullary canal. Though, excessive reaming may weaken the diaphyseal bone and increase the possibility of thermal necrosis [3].

This study was aimed to evaluate the mechanical performance of the Gamma 3 Long Nail by developing a three-dimensional finite element model of the Thai femur. A finite element model was created to determine the stress distributed on the implant and also the strain distributed on the Thai femoral with three gaps on Mid-third region. In this case, the evolution of stress and strain before, during, and after healing process could be studied.

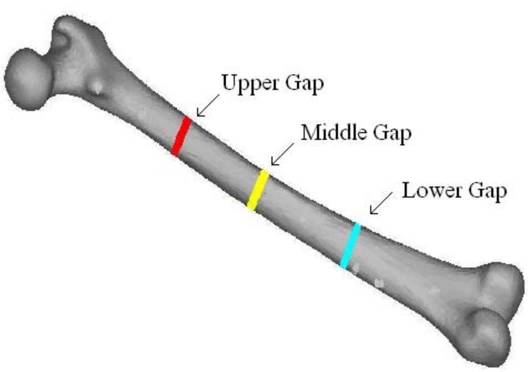
2. Materials and Methods

All finite element models were created and analyzed by MSC MARC/MENTAT 2005 finite element software package.

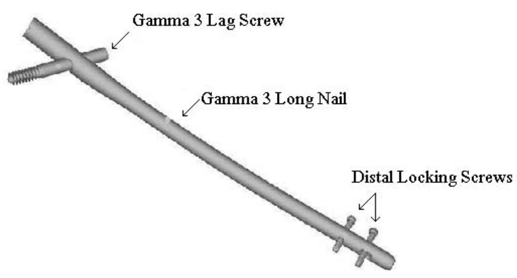
2.1 Finite element models

A three dimensional finite element model of Thai femoral was developed using Computed Tomography (CT scan), based on the average geometry of 108 Thai femora [4]. Four-noded tetrahedral elements were used to create a model the Gamma 3 Long Nail and the femur. The fractures were created as 5 mm gaps in the Mid-third region (upper, middle and lower gap).

The element edge length between the bone and the nail was by 1 mm. The distance between the distal locking screw and distal locking screw hole was by 0.5 mm. The femur-implant model had a total of 147,738 nodes and 621,205 elements.



(a)



(b)

Fig.1 (a) Thai femoral bone with three gaps, (b) Gamma 3 Long nail with lag and distal screw locking

2.2. Material properties

The mechanical properties were assumed to be linear elastic isotropic material. The properties were assigned to all materials involved in the model. The material properties of all models are shown in table 1.

Table 1: Material properties assigned for the finite element analysis model [5].

Model	Modulus (MPa)	Poisson's Ratio
Cortical Bone	14,000	0.3
Cancellous Bone	600	0.2
Connective Tissue	3	0.4
Initial Connective Tissue	100	0.29
Titanium alloy	110,000	0.3

2.3. Boundary conditions

The femoral model was fully fixed at the distal end. A walking load was used in this study as shown in table 2. Muscles loading at the hip joint for walking were derived from Heller M.O., et al [6] as shown in table 3.

Table 2: List of condition was performed in this study.

Case	Femur	Fracture zone
1	Intact	-
2	Fractured	Upper
3	Healing*	Upper
4	Fractured	Middle
5	Healing	Middle
6	Fractured	Lower
7	Healing	Lower

* The morphology occurring the fourth week of healing process.

Table 3: Muscles loading at the hip joint BW=836 N

Force	x	y	z	Acts at Point
hip contact	-54	-32.8	-229.2	P0
intersegmental resultant	-8.1	-12.8	-78.2	P0
abductor (1)	58	4.3	86.5	P1
tensor fascia latae, proximal part (3a)	7.2	11.6	13.2	P1
tensor fascia latae, distal part (3b)	-0.5	-0.7	-19	P1
vastus lateralis (4)	-0.9	18.5	92.9	P2

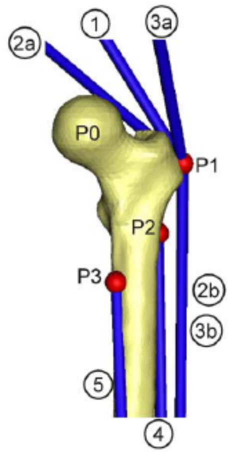


Fig.2 Shown point of muscles loading were act at the femoral bone [6]

3. Results

3.1 Stress distribution

The risk of the implant failure could be observed by maximum von Mises stress. The stress distributed on the nail under walking load was shown in table 4.

The stress distributed to the nail was characterized by bending superimposed onto axial compression and torsion. From table 4, the stresses distributed on the implant would decrease throughout the healing process. The maximum von Mises stress occurred in the region where the nail and lag screw were in contact.

3.2 Strain distribution

The proper strain value for the bone remodeling, with natural healing mechanisms in the early stage of fracture, must be between 25,000-30,000 microstrain [7-8].

The maximum equivalent total strain of the proximal femur occurred around lag screw hole and fractured gap. Table 5 represented the magnitude of maximum total strain. Fig 3 showed strain distributed on the fracture gap.

Table 4: Maximum von Mises stress on the Gamma 3 Long nail.

Gamma 3 Long Nail	Stage of healing	Fracture zone	Maximum von Mises stress (MPa)
Lag screw Hole	Fractured	Upper	1700
Distal screw hole 1	Fractured	Lower	800
Distal screw hole 2	Fractured	Middle	450
Lag screw	Fractured	Upper	225
Distal screw 1	Fractured	Middle	1200
Distal screw 2	Fractured	Middle	1300

Table. 5 Maximum Equivalent total strain in the proximal femur. (μϵ)

Case	Fracture zone		
	Upper	Middle	Lower
1	1,598	1,402	831
2	300,048	248	354
3	99,883	813	650
4	419	393,765	498
5	1,165	83,466	461
6	1,014	701	304,507
7	1,438	1,071	47,827

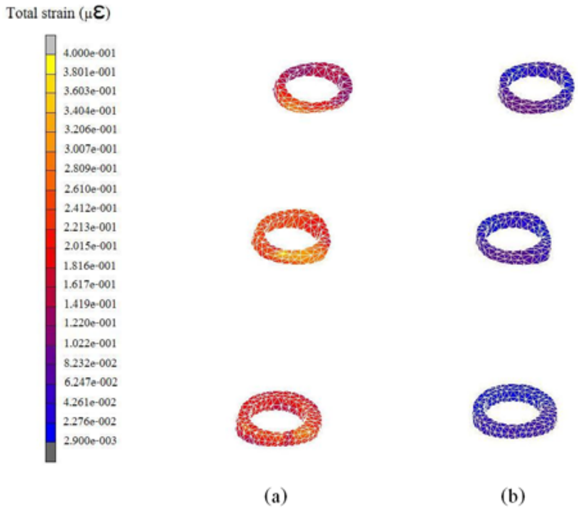


Fig.3 Shown the equivalent total strain in the fracture zone: (a) in connective tissue stage (week 1) and (b) in initial connective tissue stage (week 4)

4. Discussion

4.1 Gamma 3 Long Nail

Finite element analysis is an acceptable tool in evaluate the mechanical performance of many orthopedic implants [9-12]. In early stage of fracture healing, the stress distributed on the implant was over the range of the yield stress (Yield stress of Titanium alloy is 870 MPa) [13-16]. It was not safe to walk with full-weight bearing as it increased the risk of the implant failure.

The patients are recommended to use the crutch and in the early stage of healing process. The crutch and walker could help decreasing 51 percent of full weight bearing [17] under walking load.

4.2 Femoral bone

From numerical results, it could be observed that the early stage of the healing process showed more than 30,000 microstrain of strain value. Therefore, the bone remodeling by natural healing mechanisms is slightly slower because in the natural healing process, the maximum equivalent total strain should not be over than 4,000 microstrain for a good result.

5. Conclusion

The result showed that the maximum equivalent total strain occurred in the middle gap fracture because the narrowest cross section area where the load sharing was more than the other region and the result should be compared with the finite element analysis with the results from the experiment by mechanical testing device.

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