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Biomechanical Study of Femoral Bone after Proximal Bone Tumor Removal

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Abstract. Proximal femur is connected between pelvis and the lower extremity to carry the body weight that transfer from the upper body to the lower part. The patients, had the proximal femur bone tumor had a problem in daily activities. The most treatment for bone tumor has two methods as radiation and surgery method. The surgeon removed the bone tumor, replaced with the other proximal femur and fixed by dynamic hip screw and four screws fixation. This study aim to analyse the postoperative results after surgery with finite element analysis, were divided into six cases as the same size proximal femur, 15% and 30% small proximal femur, 15% and 30% large proximal femur and the same size proximal femur constructed by polymethyl methacrylate (PMMA). The result were shown the maximum strain on the small size higher than another cases under walking and stair-climbing load and the same size proximal femur constructed by PMMA had the lowest maximum equivalent of total strain. The surgeon should be replacing the proximal femur with the same or the larger size of femur or the same size constructed by PMMA for a good clinical result.

1. Introduction

The patient with a giant cell tumor at proximal femur had a problem in daily activities[1, 2]. The most popular treatment was radiation and surgery depended on the surgeon's decision. This study was focus on the surgery method. After the surgeon removed the bone tumors, it will replace with another proximal femur to restore the function of hip joint. The problems of size and inclination angle [3] of femur affect the strain concentration that made the bone function loss and bonefracture.

This study aims to evaluate the strain distribution on the femoral bone after remove bone tumor at the proximal part and replace with another femur, which was fixing the same inclination angle. The replaced femur varied six sizes as original proximal femur, smaller two sizes and larger two sizes than the original bone and equal the original but construct from biomaterial namely polymethylmethacrylate(PMMA). The results are a guideline for the surgeon's decision to plan the surgery process.

2. Materials and Methods

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2.1 Bone modeling

The femur and tibia bones were created from the computerized tomography (CT) data and reconstructed with ITK-SNAP program. The three-dimensional model was shown in figure 1.

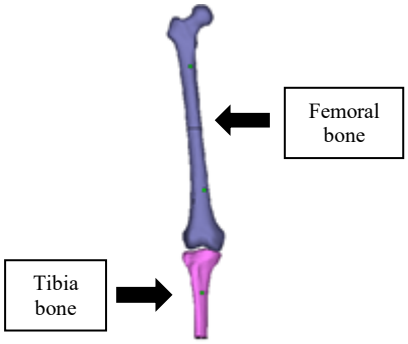


Figure 1.3D bone model.

At the knee joint, three-dimensional models of meniscus and four ligaments to connect between distal femur and proximal tibia as anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL) and lateral collateral ligament (LCL)was drawn with SolidWorks software with actual shape and anatomical position. The model of meniscus and four ligaments were shown in figure 2 and 3 respectively.

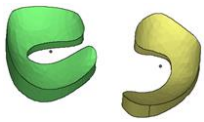


Figure 2.3D model of meniscus.

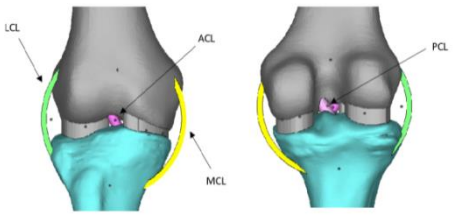


Figure 3.3D model of four ligaments.

2.2 Implant model

The implant used to fix the proximal femur after bone tumor removal was a dynamic hip screw included lag screw, side plate with barrel and cortical screws. The model of dynamic hip screw was created with SolidWorks software as shown in figure 4.

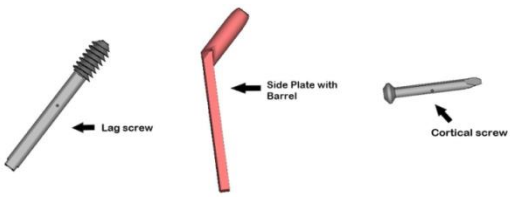


Figure 4.3D model of dynamic hip screw.

2.3 Material properties

All models in this study were assumed homogeneous, isotropic and linear elastic. Young's modulus and Poisson's ratio of materials were shown in table 1.

Table 1. Material properties of bone-implant model [4,5,6].

Material	Young's modulus (MPa)	Poisson's ratio
Cortical bone	14,000	0.30
Cancellous bone	600	0.20
Meniscus	12	0.45
ACL	345	0.40
PCL	345	0.40
MCL	345	0.40
LCL	332.2	0.40
Stainless steel	200,000	0.30

2.4 Boundary condition

The body weight act on the top of femoral head and the muscular force act on the proximal part under two conditions as walking and stair-climbing condition [7]. The position of body weight and muscular force was shown in figure 5 and 6 and the amplitude was shown in the table 2.

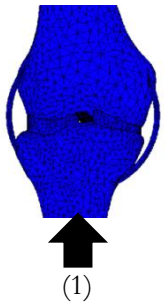


Figure 5. Fix displacement of boundary condition act on the proximal tibia.

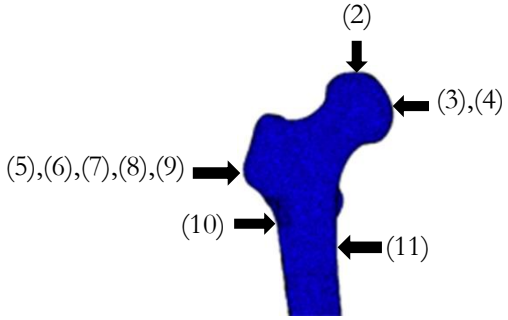


Figure 6. The position of body weight and muscular force act on proximal femur.

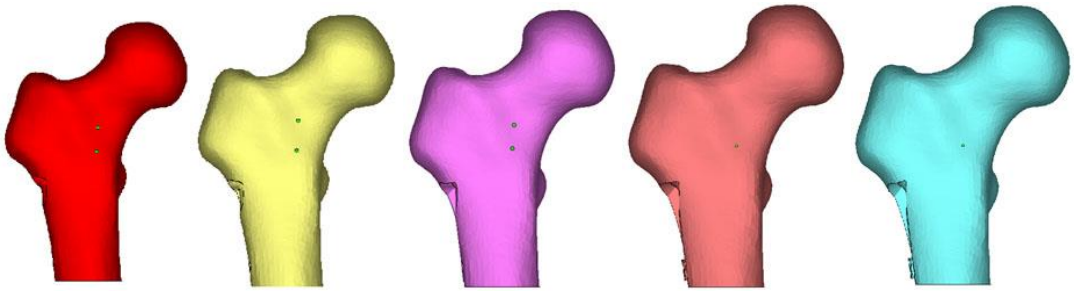
Table 2. The amplitude of force under walking and stair-climbing condition [7].

Position	Force	Walking			Stair-climbing		
		F_X (N)	F_Y (N)	F_Z (N)	F_X (N)	F_Y(N)	F_Z (N)
1	Fix displacement	0	0	0	0	0	0
2	Body weight	0	0	-836.0	0	0	-847.0
3	Hip contact	-54.0	-32.8	-229.2	-59.3	-60.6	-236.3
4	Intersegmental resultant	-8.1	-12.8	-78.2	-13.0	-28.0	-70.1
5	Abductor	58.0	4.3	86.5	70.1	28.8	84.9

6	Ilio-tibialtract,proximal part	-	-	-	10.5	3.0	12.8
7	Ilio-tibialtract,distal part	-	-	-	-0.5	-0.8	-16.8
8	Tensor fascia latae,proximal part	7.2	11.6	13.2	3.1	4.9	2.9
9	Tensor fascia latae,distal part	-0.5	-0.7	-19.0	-0.2	-0.3	-6.5
10	Vastuslateralis	-0.9	18.5	92.9	-2.2	22.4	-135.1
11	Vastusmedialis	-	-	-	-8.8	39.6	-267.1

2.5 Cases analysis

The replaced proximal femur varied five sizes: the smaller size was replaced proximal femur with 70 and 85 percentage, the larger size was replaced proximal femur with 115 and 130 percentage and the equal size constructed from PMMA as shown in figure 7. All cases analysis were shown in table 3.



(a) (b) (c) (d) (e)

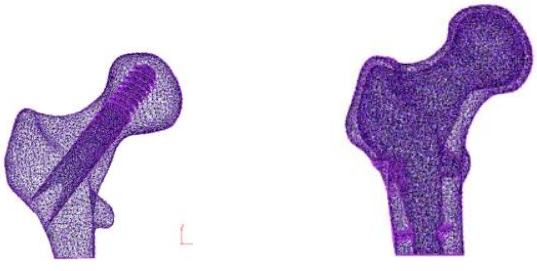
Figure 7. The model of proximal femur: (a) 70%, (b) 85%, (c) 100%, (d) 115% and (e) 130%.

Table 3. Cases analysis.

Cases	Model	Condition
1	70% Proximal femur	Walking
2	85% Proximal femur	Walking
3	100% Proximal femur	Walking
4	115% Proximal femur	Walking
5	130% Proximal femur	Walking
6	PMMA Proximal femur	Walking
7	70% Proximal femur	Stair-climbing
8	85% Proximal femur	Stair-climbing
9	100% Proximal femur	Stair-climbing
10	115% Proximal femur	Stair-climbing
11	130% Proximal femur	Stair-climbing
12	PMMA Proximal femur	Stair-climbing

2.6 Mesh generation

MSC software package was usedto generatethe mesh model of femur, tibia, meniscus and all ligaments with four-node tetrahedral element as shown in figure 8.



(a) (b)

Figure 8. Mesh model of: (a) Cancellous bone of femur and (b) Cortical bone of femur.

Total number of nodes and elements of 10cases analysis under walking and stair-climbing was shown in table 4.

Table 4. Total number of nodes and elements.

Cases	Nodes	Elements
1 and 7	84,412	363,917
2 and 8	88,591	384,262
3 and 9	90,502	393,322
4 and 10	101,052	443,140
5 and 11	110,479	489,758
6 and 12	96,060	427,306

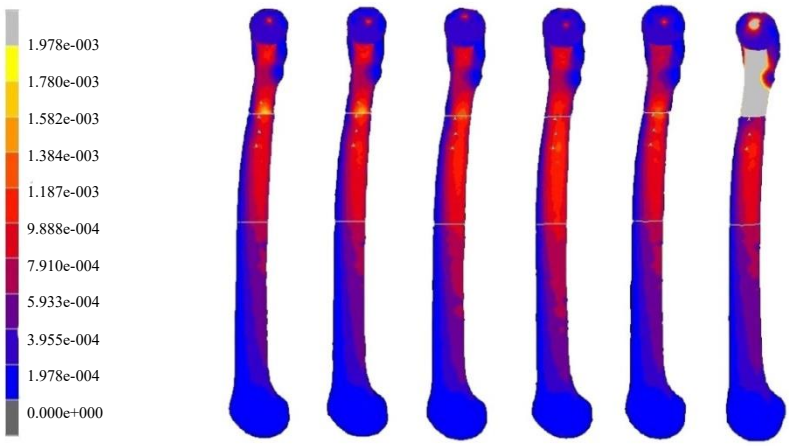
3. Results and Discussion

3.1 The maximum equivalent of total strain on femur under walking and stair-climbing condition
The maximum equivalent of total strain on femur of all casesunder walking and stair-climbing condition was shown in the table 5.

Table 5.Maximum equivalent of total strain under daily activities.

Cases	Maximum equivalent of total strain (με)	
	Walking	Stair-climbing
70% Proximal femur	1,977.58	2,983.08
85% Proximal femur	1,762.85	2,350.92
100% Proximal femur	1,567.76	2,178.84
115% Proximal femur	1,273.99	1,312.73
130% Proximal femur	1,519.68	1,477.85
PMMA Proximal femur	1,134.97	1,256.61

The stain distribution on femoral bone of all cases under walking load was shown in figure 9. The strain concentration occurred at the region contact between the original bone and replaced femur because the changing sizes affect the strain distribution.The closest maximum equivalent of total strain of 100% proximal femur is the model of 130% proximal femur that the best option to change after removed the bone tumor. If considering the suitable size, the PMMA proximal femur is the same size of the original bone that was proper to replace for restore the hip joint function.



(a) (b) (c) (d) (e) (f)

Figure 9. The strain distribution on femoral bone under walking load: (a) 70% Proximal femur, (b) 85% Proximal femur, (c) 100% Proximal femur, (d)115% Proximal femur, (e) 130% Proximal femur and (f) PMMA Proximal femur.

The stain distribution on femoral bone of all cases under stair-climbing load was shown in figure 10.The strain concentration occurred at the region contact between the original bone and replaced femur same as under walking load. The maximum equivalent of total strain occurred on femoral bone under stair-climbinghigher than walking load because more muscular force act on proximal femur than under walking condition.

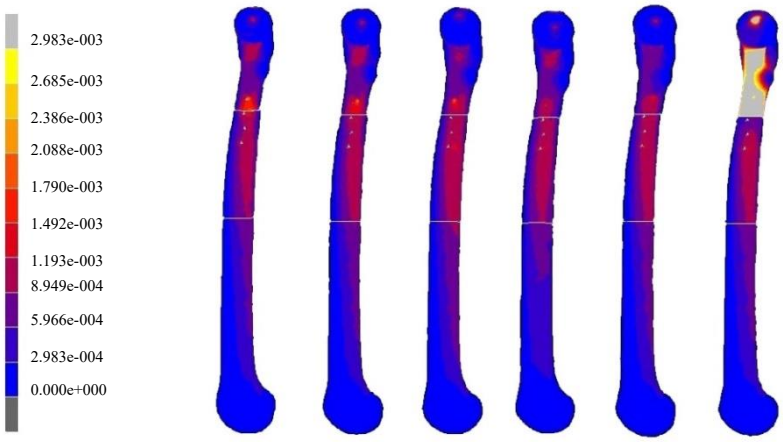


Figure 10. The strain distribution on femoral bone under stair-climbing load: (a) 70% Proximal femur, (b) 85% Proximal femur, (c) 100% Proximal femur, (d)115% Proximal femur, (e) 130% Proximal femur and (f) PMMA Proximal femur.

4. Conclusion

The trend ofequivalent of total strain distributionhad higher value in smaller bone than larger bone that shownthe larger bones were suitable for treatment in bone tumor removal. All cases shown the maximum strain distribution lower than 25,000 microstrain (με) [7, 8] that safe for bone damage after replaced proximal femur. To reduce the chance of bone function loss for mismatchingsize, the PMMA proximal femur from reverse engineering and rapid prototype as shown in figure 11 was a best choice to replace for the proximal femur removal.



Figure 11. The mirror proximal femur from reverse engineering and rapid prototype had shown the same size: (a) Original bone and (b) Mirror bone.

The mirror proximal femur was used to construct the silicone mold as shown in figure 12 for the surgeon to construct the PMMA proximal femur that had the same size and same inclination angle to protect the bone function.

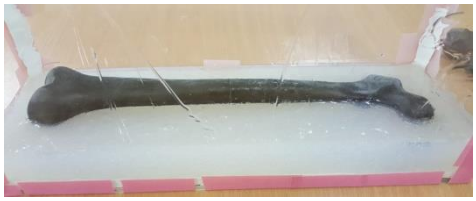


Figure 12. The silicone mold for construct the PMMA femur.

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