The Effect of Distal Femur after Replace with Biomaterials: Finite Element Analysis

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Abstract

Giant cell tumors are frequently detected at the lower end of thighbones (femurs). Surgery is the most effective treatment for these tumors. However, it is based on surgeons' experiences to remove the area of bones containing the giant cell tumors (excision) and then replace them with biomaterials. Finite elements analysis was employed in this study to analyze the maximum von Mises stress on different biomaterials at distal Thai femurs. The distal femoral bone models were divided into ten parts and then the different parts of the bones were replaced with biomaterials, namely Polymethylmethacrylate (PMMA) and Hydroxyapatite (HA). The stresses caused from the biomaterial replacements were analysed under walking and stair climbing conditions. In all conditions, the maximum von Mises stress of PMMA increased as the number of replacement increased while the maximum von Mises of HA gradually increased to the highest level in four parts replacement; then dramatically decreased in the latter five parts replacement; and became relatively stable in further replacement. Although the von Mises stress of HA reduced after five parts replacement, it was still higher than the maximum von Mises stress of PMMA. Therefore, HA might be better than PMMA in bone replacement since it could resist to higher force. Using HA could also minimize the bone excision which corresponds to the surgeons' decision. In addition, finite elements analysis seems to be a useful tool combining with surgeons' experience to validate a suitable biomaterial or an appropriate procedure for a better result in bone surgery.

Keywords: Distal Femur, Biomaterials, Finite Element Analysis.

1. Introduction

The femur or thigh bone is the longest and the largest bone in the body [1], which it is subjected to the most of loading during daily activities and crucial for skeletal mobility [2]. The giant cell tumors are often seen in the distal femur and proximal tibia. They are one of the rare bone tumors that more frequently affect women

[3, 4]. If the tumors are not treated, they will continue to grow and damage the bones. Curettage combined with cementation or allograft supplementation is commonly considered to be a therapy for giant cell tumor of bone [5]. Besides curettage, surgery has been proven to be the most effective treatment for the giant cell tumors [6]. The surgery normally depends on surgeons' decisions. The surgeons will decide to eliminate only tumor or tumor with partial bones from their experiences. Therefore, this study used finite element to analyze an appropriate bone surgery for patient. The results from this study could be used together with the decision of surgeons to make the best result in bone tumor therapy.

2. Materials and Methods

The finite element models of the implanted specimen were used for a preliminary analysis of biomaterials. All finite element models were constructed and analyzed by using MSC Marc/Mentat 2005 package.

Three-dimensional finite element models of Thai femur used in this study derived from one hundred and eight Thai cadaveric femur (which kindly provided by the Department of anatomy, Faculty of Medicine Siriraj Hospital). The samples were from 26 males, 22 females and 12 unknown genders with age range from 22 to 83 years (average, 48.5) at the time of death [7]. The femur model comprised of cortical bone and cancellous bone. The distal femoral bones were divided into ten parts by using four-node tetrahedral elements to model the femur. The finite element models of Thai femurs had a total of 39862 nodes and 147538 elements.

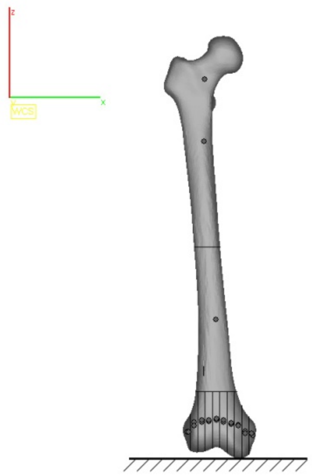

Fig.1 The femur bone and biomaterial model

Material properties of all models are shown in Table 1.

Table 1. Material properties were assigned for the finite element model [8 - 10].

Model	Modulus (MPa)	Poisson's Ratio
Cortical Bone	14,000	0.3
Cancellous Bone	600	0.3
Polymethyl methacrylate	1800	0.35
Hydroxyapatite	40000	0.27

To compare the effects of two different biomaterials in bone replacement, the finite element models of femurs were divided into 10 parts and different amount of divided parts were replaced with either PMMA or HA. Boundary conditions of the femoral model set was based on the daily activities such as; walking and stair climbing [11] in order to analyze the maximum von Mises stress and maximum total strain on biomaterials and femeral bone respectively.

3. Result

The results showed that the maximum total strain values of both PMMA and HA were comparatively equal which did not excess 25,000-30,000 microstrain [12] in all conditions. It indicated that both of the materials would not cause bone damage. (The maximum total strain are 3,730.91 microstrain for walking condition and 3,780.12 microstrain for stair climbing condition)

The maximum von Mises stress of PMMA in both of the walking and stair climbing conditions tended to increase gradually when the number of replaced parts increased ranging from 1 part to 10 parts from the medial side to the lateral side as shown in Fig.2

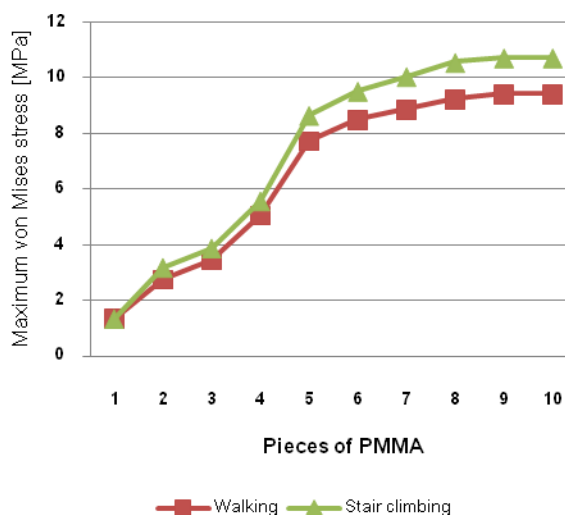

Fig.2 The maximum von Mises stress on PMMA

In HA replacement, the maximum von Mises stress increased to the highest level in the first four parts replacement from the medial side to the lateral side. Then the stress was dramatically decreased in the latter five parts replacement and became relatively stable in further replacements (Fig.3). Although the von Mises stress of HA reduced after five parts replacement, it was still higher than the maximum von Mises stress of PMMA.

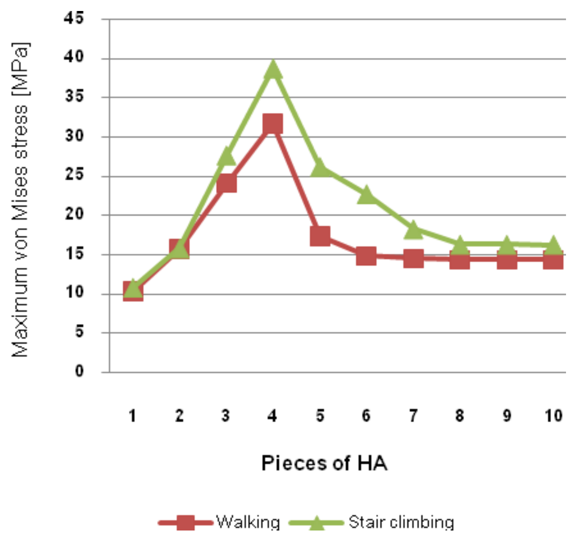

Fig.3 The maximum von Mises stress on HA

4. Discussion

4.1 comparisons of two biomaterials in bone replacement

From the results, the maximum von Mises stress and the maximum total strain from walking and stair climbing conditions showed the same trend in the same material. The maximum von Mises stress of PMMA, for example; showed the same pattern which gradually increased in both walking and stair climbing conditions. Therefore, the maximum von Mises stress and the maximum total strain mainly depended on materials rather than activities.

Each material has different strengths. According to the results, the maximum total strain in bone of both cases was relatively similar while the maximum von Mises stress and the Young's modulus of HA were higher than PMMA. These indicated that HA might be better than PMMA in terms of the loading capacity and the resistance to deformation.

4.2 HA bone replacement

The results showed that the maximum von Mises stress of HA reached the highest level when four parts of bone were replaced with HA. This phenomenon might be due to shear force and bending moment which normally have the highest value at the middle position. When the shear force and bending moment increase, the maximum von Mises stress will increase.

As HA is higher in strength than PMMA, using HA could also minimize the bone excision which corresponds to the surgeons' strategy. However, if four parts of the bone need to be excised, at least five parts should be removed in order to avoid the maximum bending stress in the area.

4.3 PMMA bone replacement

In PMMA replacement, the maximum von Mises stress was gradually increased depending on the amount of replaced parts. The more PMMA replaced, the more stress occurred. Therefore, the PMMA replacement should be minimized as much as possible to reduce the stress and a chance of replacement failure.

5. Conclusion

The finite element could be used to validate a suitable biomaterial in bone replacement. In this case, HA appeared to be the best material in bone replacement, comparing to PMMA.

In this study, the biomaterial replacement was done only from the medial side to the lateral side. The replacement from the lateral side to the medial side or the replacement of the middle part only should be experimented as well in order to obtain more data for a better result in bone surgery.

6. Acknowledgement

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7. References

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