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Finite element modeling to Aid in Refining the Rehabilitation of Amputees Using Osseointegrated Prostheses

Winson Lee[1] PhD; Laurent Frossard[1] PhD; Nicola Cairns[1] MEng; Rickard Branemark[2] PhD; John Evans[1] PhD; Clayton Adam[1] PhD; Mark Pearcy[1] PhD.

[1]Institute of Health and Biomedical Innovation, Queensland University of Technology, Australia
[2]Centre of Orthopaedic Osseointegration, Sahlgrenska University Hospital, Sweden

Abstract. The direct anchourage of a lower-limb prosthesis to the bone has been shown to be an excellent alternative for amputees experiencing complications in using a conventional prosthetic socket. After surgical implantation, amputees have to go through a weight bearing exercise to prepare the bone to tolerate forces and promote bone-remodeling. Currently, the load magnitude prescribed by the clinician is measured by a weight scale which reports only the axial force in the limb. Our previous study using a load transducer revealed that in addition to the axial force there were forces on the other axes and moments. This study develops a FE model and utilizes our load data to investigate the stress distribution at the bone-implant interface. The model shows that the stress distribution could be highly non-uniform during the exercise. Bone-implant interface stress has certain implications in pain adaptation and bone-remodeling, and a good understanding of it can assist in future attempt to refine and shorten the period of rehabilitation exercise.
Keywords: transfemoral amputation, bone anchouring prosthetics, osseointegration, weight bearing exercise, finite element modeling.

1 Introduction

Pain and tissue breakdown are sometimes experienced by amputees using conventional prostheses because of the high pressure applied from the socket to the residual limb. In addition, fitting problems are produced because of the fluctuations of the residual limb volume and the residual limb being too short. In an attempt to avoid these problems, a surgical approach for connecting a prosthesis into the femur with a titanium threaded-implant (osseointegration) was developed [1]. The implant is connected to the external prosthetic components through an abutment, which protrudes through the soft tissues and skin.

Trans-femoral amputees being fitted with osseointegrated prostheses have to undergo some specific rehabilitation exercises prior to full weight-bearing. One exercise is to apply a prescribed static load to the abutment, approximately along the axis of the residual femur using a conventional weigh-scale as force transducer. Initially 20 kg of load is prescribed, and the loading is increased incrementally until full weight can be borne without pain. The weight is decreased to a non-painful level if pain is perceived. Full weight bearing is usually achieved between 3 and 6 months after the surgical insertion of the implant and abutment.

A domestic weigh scale can display the magnitude of the vertical force only and, if the femur is vertical this corresponds to the axial force it experiences. If the limb is not vertical or is otherwise subjected to forces in the horizontal plane, these forces and the moments generated are not measured. Our previous studies using a 6-channel load transducer has revealed that in addition to the axial forces there were some forces acting on the other axes and corresponding moments [2,3]. The effects of those additional loads on bone-implant interface stresses are of interest as they impact on the process of rehabilitation.

The stresses at the bone-implant interface have been calculated in this study using a finite element (FE) model with our previous load data as input. Comparisons of the stresses are made between two loading cases: 1) A load applied on the long axis of the limb only which corresponds to the load clinically prescribed (monitored with the weigh scale); and 2) A load applied on the three axes corresponding to the “true” load (measured simultaneously by a 6-channel load transducer).

2 Methods

The forces generated during the weight bearing exercise of one trans-femoral amputee fitted with an osseointegrated fixation were measured simultaneously using a weigh scale and a 6-channel load transducer. Detailed measurement techniques have been described in [3]. Utilizing the measured load data, finite element (FE) analysis was performed in Abaqus 6.6 to investigate the bone-implant interface stresses (Figure 1). Details of the model are as follows:

Geometry: The dimensions of the commercial implant (approximately 100mm long and 20mm in diameter) developed by Dr. R. Branemark were used. Three-dimensional bone geometry was downloaded from the BEL Repository. The amputated bone had a length of 230mm measuring from the greater trochanter to the distal cut end.

Material properties: Young’s moduli of 15GPa (bone) and 110GPa (implant) were assigned.

Loadings: Two load cases were input. A prescribed axial force was 900N (Loading A), which represented nearly the full body weight of the subject; and the corresponding “true” load (Loading B) recorded by the 6-channel transducer which suggested there were lateral and posterior forces of 112.1N and 40.4N, respectively, in addition to the axial force, and with a lateral rotational moment of 13.4Nm. The femoral head was fully fixed.

Mesh: The number of tetrahedral elements reached approximately 100,000. A fine mesh was used at the interface between the bone and the implant.

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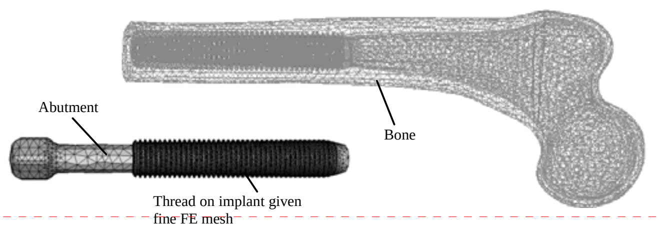

Fig 1. FE meshes for bone and prosthesis

3 Results

Loading A: The FE model shows that the von Mises stress at the implanted site of the bone is distributed quite evenly with the peak von Mises stress of 1.5MPa when the axial-only force is applied. Immediately above the proximal end of the implant the von Mises stress becomes higher reaching 3MPa.

Loading B: The stress distribution is highly non-uniform when the forces and moments are applied on the three axes (Figure 2). The peak von Mises stress at the implanted site of the bone becomes significantly higher (7.7MPa) than the axial-only loading. Some areas along the implanted site experienced very low stresses (<0.5MPa). The von Mises stresses reached approximately 9MPa immediately above the proximal end of the implant.

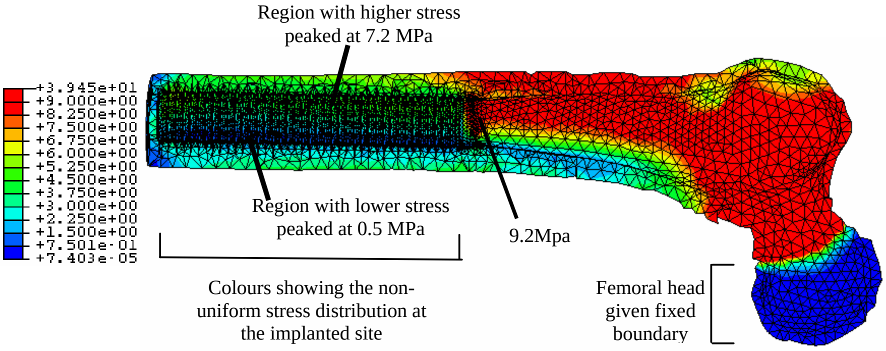

Fig.2 Section view of the bone showing the von Mises stress distribution at Loading B condition.

4 Discussion and Conclusion

This model demonstrated that the stress distribution at the bone-implant interface induced by the actual 3-dimensional loadings measured during the weight bearing exercise can be significantly different from that created by an axial-only force.

Bone-implant stress distribution could have certain implications in pain adaptation and bone-remodeling. Particularly high stresses applied to the bone should be avoided as it can produce pain. On the other hand, suitable amounts of stresses should be applied to the appropriate regions of the bone so as to prepare the amputees to walk without perception of pain and to promote bone-remodeling. Future attempts will be made to refine and shorten the period of rehabilitation exercise after the insertion of the implant and the abutment by re-distributing the stresses that favour bone-remodeling and improve bone tolerance to pain.

References

1. Branemark, R., Branemark, P.I., Rydevik, B., Myers, R.R: Osseointegration in skeletal reconstruction and rehabilitation: A review. J Rehabil Res Dev (2001) vol.38, 175-181.
2. Cairns, N., Frossard, L., Hagberg, K., Branemark, R. Static load bearing during early rehabilitation of transfemoral amputees using osseointegrated fixation. Proceedings of the 30th Annual Scientific of ISPO Australia-Australia (2006) 51-52.
3. Frossard, L., Beck, J., Dillon, M., Evans, J. Development and preliminary testing of a device for the direct measurement of forces and moments in the prosthetic limb of transfemoral amputees during activities of daily living. J Prosthet Orthot (2003) vol.15, 135-142.
4. Day, R. 3rd generation composite femur, From: The BEL Repository, http://www.tecno.ior.it/VRLAB.