Finite Element Method to Analyze the Structural Integrity of Bone receiving Implanted Prosthesis

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INTRODUCTION

It is not uncommon that traditional prosthetic socket results in skin breakdown and residual limb pain. In an attempt to solve the problems, a surgical approach for connecting the prosthesis directly into the femur with titanium implant (osseointegration) was developed. The technique of osseointegration was first successfully used in dentistry**.** However, the loads experienced by an osseointegrated lower-limb prosthesis are much higher than a prosthetic teeth. Due to disuse atrophy, significant bone loss can occur after months of using socket-prostheses [1]. The reduced bone density together with the high amount of loadings put lower-limb amputees at risk of bone fracture when they switch to use the bone-anchored prosthesis.

Our research team has previously documented the loads applied on the implant, and use finite element (FE) analysis to study the bone-implant interface stress [2,3]**.** Our current aim is to use FE methods to predict the bone structural integrity under different conditions.

METHODS

Finite element (FE) analysis was performed in Abaqus 6.6 to investigate the bone strains. The implant created in Solidworks had diameter of 20mm, thread pitch of 1.75mm, and length of 100mm. Three-dimensional bone geometry was downloaded from the BEL Repository. The bone and the implant were assumed to be perfectly tied. 3D-forces and moments occurring at heel off of the gait were applied, which were based on previous gait analysis on amputees fitted with osseointegrated prostheses [2]. Parametric analysis was performed by multiplying the axial component of the loads to up to 4 times of the normal walking loads to simulate accidentally high impact forces. Bone Young’s modulus (E) was changed from 3000 to 15,000MPa to simulate various cases of bone density (ρ) loss. Young’s modulus of 15,000MPa resembled the material property of a normal human bone [4], and that of 3000Mpa was calculated from an empirical equation of $E = k\rho^3$ [5] resembling a bone having 40% of density drop [1].

Prediction of bone failure was performed by assessing whether the bone strain was above the yield strain (1.2%) of the human femoral bone [6]. This based on previous findings suggesting that the yield strain of the bone is relatively independent of bone density change [6].

RESULTS AND DISCUSSION

High strain is found at the neck of femur. With normal walking loads applied, maximum principle strains increase when the bone density (Young's modulus) decreases, but are still below the bone yield strain of 1.2%.

However, with the bone loss of 40% and axial loads multiplied by 4 times, the maximum principle strain is over 1.2% which indicates possible bone failure (Table 1).

If a “healthy” bone (E=15,000MPa) is assumed, the maximum principle strains are well below 1.2% even the loads are multiplied by 4 times.

This study suggests the importance of assessing the bone quality for lower-limb amputees receiving osseointegrated prostheses, and rehabilitation to promote bone growth. Experimental validation will be performed. Bone density change of lower-limb amputees will be studied in more details. Different bone geometries and failure prediction theories will be attempted.

CONCLUSIONS

This study investigated the bone strain and predicted the possible structural failure in various situations. The ultimate aim of this research is to suggest guidelines for excluding lower-limb amputees having high risk of bone failure.

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REFERENCES

1. Meerkin J. D. / Queensland University of Technology PhD Thesis.
2. Lee W.C.C. et al. / Clin Biomech 22 (2007), 665-673
3. Lee W.C.C. et al. / Clin Biomech 23 (2008), 1243-1250
4. Taylor M. E./ Med Eng Phys 18 (1996), 122-131
5. Carter D. R. and Hayes W. C. / J Bone Joint Surg 7(1997), 954-962.
6. Helgason B. et al. / J Biomech 41 (2008), 1675-1681

Table 1: The effects of changing bone Young’s modulus and magnitude of load on maximum principle strain.

Case 1: Change of E while normal walking loads were applied		Case 2: Change of axial loads, while keeping E=15,000MPa		Case 3: Change of axial loads, while keeping E=3,000MPa	
Young’s modulus(MPa)	Max. principle strain	Load multiple	Max. principle strain	Load multiple	Max. principle strain
15000	0.09%	1	0.09%	1	0.32%
9000	0.13%	2	0.18%	2	0.79%
6000	0.19%	3	0.27%	3	1.14%
3000	0.32%	4	0.36%	4	1.56%