INFLUENCE OF BONE QUALITY ON THE INITIAL STABILITY OF CEMENTLESS HIP STEM IN TOTAL HIP ARTHROPLASTY

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Introduction

The Young's modulus and strength of bone varies between each individual due to differences in porosity, mineralization, and architecture. The differences between individuals can be significant depending on activities, age and disease [1-7]. This is likely to have an effect on initial stability of hip stem in total hip arthroplasty.

After the age of 30 years, bone mass decreases slowly with age, which is thought to be caused by a small deficit of osteoblast deposition relative to osteoclast resorption [2]. Ding [2] reported that reductions of as much as 40% between age of 50 and 80 years old are possible. Zioupos [3] reported that reduction of cortical bone modulus in the diaphyseal femur is about 2.3% per decade after about 30 years age. Young's modulus in cancellous bone with rheumatoid arthritis and osteoporosis has been reported to be inferior to normal bone by 47% [5] and 14% [4] respectively.

Although it is known that bone quality affects the performance of cementless hip implants, it is difficult to quantify bone quality in cadaveric femurs used in experimental studies of hip implant stability [6,7]. In finite element studies, the effect of bone quality on initial micromotion has not been studied [8,9]. Therefore an objective measure of the influence of bone quality on initial stability is not available for either preclinical or clinical purposes.

In this study, the effect of bone and stem quality on stability of the IPS stem has been studied. The objectives are (a) to look at the sensitivity of cementless stem stability to variation in bone Young's modulus (b) to determine whether current finite element method of assessing implant stability based on one femur are adequate?

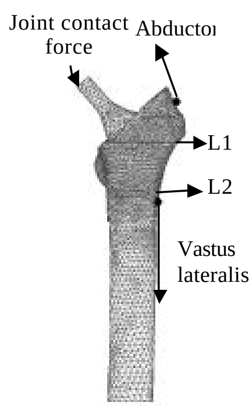
Method

A finite element (FE) model was constructed based on computer-tomography (CT) scans of a male human femur and implanted with a proximally porous coated IPS stem (DePuy, USA) made of titanium alloy. The apparent density of bone was assumed to be linearly related to the Hounsfield unit from the computed tomography scan.

The elastic modulus of the bone was assumed to have a relationship with apparent density of the form $E = 2875\rho^3$ [10], where E is the elastic modulus and ρ is the apparent density. The reduction of Young's modulus to study the effect of poor quality bone on initial stability was done by systematically scaling the coefficient of the density-Young's modulus relationship with a constant to achieve reduction of Young's modulus between 10 and 40% (Table 1).

Reduction in modulus	0 %	10 %	20 %	30 %	40 %
Coefficient	2875.0	2587.5	2300.0	2012.5	1725.0

Table 1. Modified coefficient in $E = 2875\rho^3$ for different bone qualities



	Force component (N)		
	A-P[1]	M-L[2]	I-S[3]
Joint force	370	225	1573
Abductor	-444	-104	554
Vastus lateralis	6	-127	-638

[1] A-P = Anterior-posterior for +ve
[2] M-L = Medial-lateral for +ve
[3] I-S = Inferior-superior for +ve

L1 = below neck resection level
L2 = end of porous coating

Figure 1. Joint and muscle forces for single leg stance during walking. Results are reported for level L1 and L2.

The joint contact force and muscle forces for single leg stance during walking [11] were applied to the model, as shown in Figure 1. The micromotion values are reported for the interface bone in level L1 and L2 (Figure 1). At each of these levels, the percentage area under 50 μm micromotion (defined as the ratio of the distance between nodes with micromotion under 50 μm and the perimeter of the bone-stem interface at that level) is reported as well. 50 μm is choosen as the threshold for bone ingrowth [8].

Results

Figure 2 shows a nonlinear increase in maximum micromotions with respect to systematic reduction in Young's modulus. In comparison to the 100% model, the maximum micromotions in the 60% model increased by 64 and 65% at L1 and L2 respectively. The maximum micromotion of about 55 μm in the 100% model is quite near the threshold of bone ingrowth of 50 μm, but has been elevated to about 91 μm in the 60% model.

The predicted area under 50 μm decreased with reduction in Young's modulus, which is consistent with increase in maximum micromotion (Figure 2). At L1, the predicted areas of bone ingrowth in the 100 and 60% models are 88 and 28% respectively. At level L2, the predicted areas of bone ingrowth in the 100 and 60% model are 87 and 59% respectively. Reduction in Young's modulus brought about greater reduction in area of bone ingrowth proximally than distally. This could be due to the stiffer cortical bone envelope distally.

It is interesting to note that similar increase in maximum micromotion in levels L1 and L2 due to reduction in Young's modulus does not bring about similar reduction in predicted area of bone ingrowth. The micromotion distribution at L1 is such that the percentage area closer to 50 μm is greater than at level L2. This is the reason for the greater reduction in area under 50 μm at level L1 when Young's modulus is reduced.

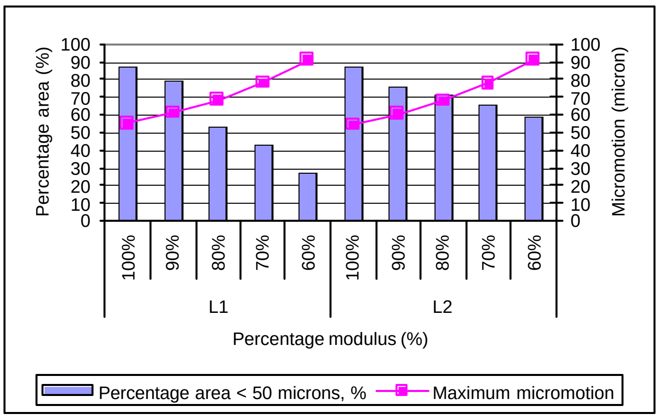


Figure 2. Micromotion at L1 and L2. Maximum micromotion increases and areas with micromotion under 50 mm decreases as the stiffness of bone decreases.

Discussion

Initial stability of the hip stem is affected by bone quality. The result showed that 65% increase in maximum micromotion is possible with a reduction of 40% Young's modulus. The effect of bone quality becomes more crucial if a significant percentage area of the implant is already performing near the threshold of bone ingrowth in normal bone. A hip stem design that has most of its area performing near the threshold of bone ingrowth in normal bone is most likely to have very little bone ingrowth if implanted into a femur with significantly poorer bone quality, as shown in our result when comparing L1 and L2.

One of the possible longer term concern in design that fail to achieve significant initial fixation in a poor quality bone environment is that upon full loading, the small patches of bone ingrowth will have to support excessive shear and tensile stresses. Over a period of time, fatigue fracture might break these patches of support, and lead to a purely press-fit loading. Press-fit loading has been reported to load the interface bone with higher stress than cemented or bone-ingrown stem [12]. Taylor [12] reported that excessive interface cancellous bone stresses may be responsible for migration of hip stem, and excessive migration may lead to future aseptic loosening of hip stem [13].

The present study showed that the initial stability of a hip stem is significantly influenced by the quality of femoral bone. Therefore, it is imperative that in preclinical finite element analysis, new hip stems design should be verified for a range of femur qualities, especially the poorer quality femur. This work should be extended to look at other bone variation using a larger CT-scan database.

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