Determination of relative motion between bone and implant in uncemented femoral surface replacements using a finite element model

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Introduction

Cemented femoral surface replacements are becoming a popular option for younger and more active patients. Uncemented heads are also being developed, which may offer less complicated implantation and long term stability. They rely on a conical interference to achieve sufficient stability for bony ingrowth [1]. The aim of this study was to investigate the effects of the magnitude of interference fit, the friction coefficient between implant and bone and the bone stiffness on the relative motion between bone and implant during dynamic loading.

Methods

A finite element contact model (Ansys 10) was developed to estimate the effect of the three parameters on relative motion. The proximal femural bone geometry was based on a CT scan (voxel size 0.4×0.4×1.0mm). Local material properties Young's modulus and shear modulus were assigned to the elements based on their local density (non-homogeneous) or the mean density (homogeneous) while Poisson ratio kept constant. Carter's material law [2] was compared with an orthotropic material law developed from experimental compression measurements on bone cubes from human femural head specimens (n=5). Implantation was simulated by displacing the implant onto the bone, to achieve effective radial interference of 0-150µm. The measured bone density was then varied between 20-100% and the friction coefficient from 0.39-0.82 [3]. The head was loaded with typical gait forces (1945N heel-strike, 1350N toe-off [4]), combined with experimentally determined friction moments for metal-on-metal resurfacing implants in a hip simulator (5.5Nm heel-strike, 7.0Nm toe-off). The displacements on the contact surface were used to determine the motion between bone and implant. Relative interface translation vectors were derived using custom post-processing.

Results and Discussion

Relative motion magnitudes were highest for the smallest radial interference but reduced rapidly with increasing interference (Fig. 1). Already 50µm of effective interference reduced mean relative motion below 50µm and, such, should allow bony ingrowth. Small interferences allow potentially damaging implantation forces to be minimised. Peak motions were generally observed in anterior and posterior regions especially for the orthotropic material law. The use of an orthotropic homogeneous formulation resulted in slightly greater motion than for isotropic or non-homogeneous, indicating that the bone stiffness distribution should be correctly modeled. Carter's (general, skeletal) material formulation resulted in stiffer bone than for the experimentally determined formulation especially for the femural head resulting in lower relative motion for similar interferences due to the higher radial forces. A 50% reduction in friction coefficient led to an increase in motion of 11%; an increase in motion of 62% was observed for a 50% reduction in bone density. Thus, assuming realistic ranges, the bone quality has a greater influence on relative motion than friction. Greater relative motion was always observed for heel strike rather than toe-off, similarly to other studies applying force only.

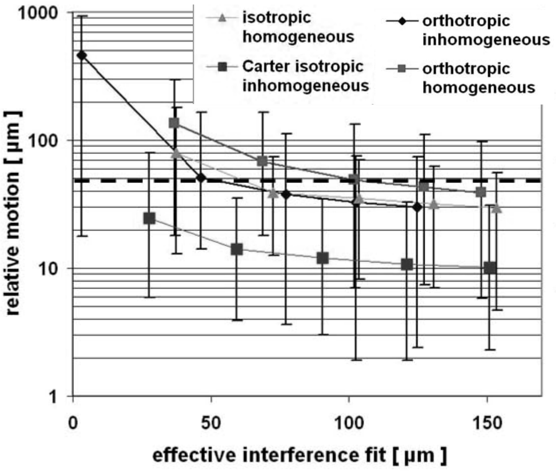

Fig 1.: Max, mean and min relative motion for different interferences and materials (heel-strike).

References

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[2] Carter, DR; Bone Joint S. Am. 1977 Oct; 59(7)
[3] Grant, J; ORS, Vol. 29, San Francisco 2004
[4] Bergmann, G; J Biomech. 1993 Aug; 26(8)