EFFECT OF STEM SURFACE FINISH AND DEBONDING ON LOAD TRANSFER TO THE CEMENT AND FEMUR IN A HIP REPLACEMENT: A VISCOELASTIC FEA MODEL

Methods: The details of the shape and density of the femoral bone were obtained by digitizing a cadaver femur using a Quantitative Computed Tomography (QCT) scanner. This data was input into the PATRAN finite element program and a 3-D model of the intact femur was generated. The appropriate positioning of the stem was determined using templates on conventional radiographs. A finite element model of that stem was then generated, using blueprints obtained from the manufacturer, and the stem-model was “inserted” into the femur-model in the computer. The femur, the stem and the cement layer were represented by 23,968, 15,644 and 14,111 eight-node brick elements, respectively. The stem-cement interface was modeled with 3584 Coulomb friction interface elements, either as fully bonded, or debonded with the frictional coefficient varying from 0.05 to 0.25 in increments of 0.05. The elastic moduli of the bone elements were determined individually by their local densities from the QCT scan.2 The cement mantle was assigned viscoelastic (creep) properties that had been determined individually by their local densities from the QCT scan.2 The cement mantle was assigned viscoelastic (creep) properties that had been measured experimentally.3 The stem was assigned elastic modulus of 200 GPa. Loads of 3200N and 2150N were applied to the femoral head and greater trochanter, respectively.

Results: Although the insertion of the prosthesis caused a reduction in the stresses within the bone for all bonding conditions compared with the intact bone model, the debonded smooth stem resulted in more load transfer to the bone than the fully bonded and/or rough surfaces. Under the load, the strain energy of the bone sections at the proximal region with the fully bonded prosthesis was as low as 25% of that with the intact femur. The debonded smoother stem produced higher strain energy of the bone. As shown in Fig 1, which was normalized with respect to the strain energy with the fully bonded stem-cement interface, the increase in strain energy with the smooth surface occurred particularly in the proximal region. As would be expected, the smooth stem also generated higher stresses within the cement layer, but the maximum values (37 Mpa) were below the failure strength (~60 Mpa). Including 100 hours of creep of the cement in the model (Fig.3) had little effect on the magnitude and distribution of load transfer and stresses within the cement compared to those for linear elastic cement.

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Discussion: The results of this model are consistent with the concepts that, once debonded, a rough-surfaced stem may be susceptible to greater interface micromotion, leading to more cement debris and possibly micro-cracks at the cement mantle. In addition, the present results indicate that a rough stem, whether bonded or debonded, may transfer substantially less load to the proximal femoral bone, with the difference varying from 20% to 90%, depending on the coefficient of friction between the stem and the cement mantle (i.e., the degree of polish of the stem) (Fig 1). The small effect of cement creep on the load transfer and cement stresses demonstrated by this model were consistent with our previous study.6 However, factors not yet included in the model could substantially increase the effect of creep in vivo. For example, including porosity of the cement layer may allow a greater change in cement volume under load, in turn allowing greater subsidence of the stem and greater changes in the cement stresses and bone loading.

Introduction: For the femoral component of a cemented hip prosthesis, the shape of the stem and its surface texture are key factors affecting its clinical performance. However, there is considerable controversy regarding the optimum design. In the present study, a non-linear finite element analysis was performed to investigate the mechanical consequences of altering the surface finish of the stem. This initial model was based on the Exeter prosthesis to permit comparison of the output of the model with the known clinical performance of a stem for which the shape has not changed substantially since 1970, but the surface finish was modified from smooth, to matte between 1976 to 1986 with poor clinical results, and subsequently smooth.1