DOES CHOICE OF FEMORAL CEMENT MANTLE THICKNESS DEPEND ON BONE DENSITY?

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Introduction

The cement mantle is an important contributory factor in the failure of cemented total hip replacements. Failure of fixation is often associated with cement fractures. Although there is broad consensus as to the acceptable range of cement mantle thickness, surgical practice is not consistent. Surgeons in the Europe generally prefer a thinner cement mantle than those in the USA. The aims of this study were to compare the performance of different thicknesses of cement mantle using finite element analysis and to discover if this was related to the quality of cancellous bone in the proximal femur.

In this study, we use a linear-elastic model of the implanted femur to give a prediction of the stresses in the cement mantle and in the femoral cortex. These measures give an indication of the relative rates of cement cracking and loss of bone stock due to stress shielding. In order to assess the reliability of our model in representing patients with different bone densities, we use a range of cancellous bone stiffnesses.

Materials and methods

Two cadaveric femora from the same donor were sized, reamed and implanted with identical plastic replica femoral components following standard surgical technique for the Stanmore Hip system. One was prepared using rasps designed for use in the UK, over-reaming by ~2 mm, the other using rasps designed for use in the US, over-reaming by ~5 mm. Serial CT-scans were used to create three-dimensional geometric models of the implanted femora.

Two finite element meshes were hand-built in MSC.Marc finite element software, incorporating cortical and cancellous bone, bone cement and prosthesis. Each model consisted of 10,000 eight-noded brick elements, with a fully bonded stem-cement interface. The thick and thin cement mantles had thicknesses of 2.5 mm and 1.0 mm respectively, in regions where thickness is affected by rasp size. Models were identical in the distal medullary canal. Cortical bone was modelled as transversely isotropic, with longitudinal and transverse moduli of 17.0 GPa and 11.5 GPa. Bone cement was given a modulus of 2.7 GPa. Loading conditions were chosen to represent the heel-strike phase of gait.

In order to assess the impact of variability in patient bone density, cancellous bone modulus was varied between 0.06 and 2.90 GPa.

Results

Von Mises’ equivalent stress was examined on the external surface of the cortex and maximum principal stress on the internal surface of the cement mantle. The lowest cortical bone stresses were found proximally, as shown in Figure 2, and the highest cement stresses around the distal tip of the prosthesis. In the proximal cortex, equivalent stresses observed medially and laterally were higher with a thick cement mantle. Distally, lower cement principal stresses were observed in the thick cement mantle, as shown in Figure 3.

Conclusion

Our results demonstrate proximal stress shielding which is most pronounced in the calcar region, in agreement with clinical findings. The thicker cement mantle leads to less stress shielding in this region. Cement stresses, which are highest around the distal tip of the prosthesis, are larger in the thin cement mantle. This would suggest a higher rate of cracking in thin cement mantles. Both of these effects are observed over a full range of cancellous bone stiffness, although both are more pronounced in patients with low bone density. Patients with very low bone density and thin femoral cement mantles are therefore most at risk of both cement fracture and bone resorption due to stress shielding.

Discussion

Variation in the elastic modulus of cancellous bone caused a spread in stresses. With the highest cancellous modulus, there was little difference between the two models. As this modulus was reduced, stress differences between the models were increased. Peak distal cement stresses were lower and proximal calcar stresses higher in the thick cement mantle, for all cancellous bone moduli.

References