Introduction

Whilst specimen-specific finite element (FE) models of bone have shown good agreement with experimental results, the representation of cement-augmented bone for orthopaedic applications remains a challenge. In previous studies, the bone-cement interface has been represented in simplified forms using continuum level models, but this has been shown to lead to large overestimations in the predicted stiffness [1]. Therefore, this study investigated different methodologies for representing cement augmentation and for understanding the micromechanics of the cement-bone interface using two scales of specimen-specific FE models. A novel morphological validation method for the µFE models was also developed.

Methods

Cylindrical synthetic bone (Sawbone, Sweden) specimens of two different sizes (24mm diameter, 19mm height and 6mm diameter, 12mm height) were augmented using PMMA cement (Craniplastic, Depuy-CMW, UK). The larger specimens were imaged using micro-computed tomography (µCT) and tested under compression. Continuum level FE models were generated from the images using three different methods. (I): both synthetic bone and cement composite regions were assigned homogenous properties; (II): the synthetic bone region was assigned properties based on the image greyscale whilst the composite region was assigned as pure cement; (III): both regions were assigned properties based on the image greyscale. The FE predicted stiffnesses using the different methods were compared with experimental results. Mesh convergence and material sensitivity tests were also undertaken.

The smaller size specimens were loaded incrementally under compression inside a µCT scanner and imaged initially and after each loading stage. µFE models with element size 50µm were generated from the unloaded µCT images using commercial software (Simpleware, UK). Both the cement region and Sawbone 'trabeculae' were considered to be homogenous and linearly elastic. The effect of using different friction properties at the cement/foam interface was studied. Vertical section slices were taken through the deformed FE models at each loading stage and compared with the corresponding µCT images using an in-house code. All models were solved using ABAQUS (Simulia Corp, USA).

Results

From the continuum level models, the greyscale related method (Method III) achieved good agreement between FE predicted stiffness values and those found experimentally (error <5.3%), which was superior to Methods I and II (error =18.3 and 12.2% respectively).

From the µFE models, the maximum effects of different interaction properties at the interface on the applied force, stress and morphological deformation were found to be less than 4%, 1% and 1% respectively. The differences between the FE-predicted trabecular deformation and the experimental images were found to be small with low strain, but tended to increase with higher strain.

Discussion

The results of this study show the superiority of using grey-scale based methods over homogenous material properties for both bone and cement. The trabecular level models were found to be capable of representing cement-augmentation at a smaller scale and, in this pure compression case, the interaction properties at the cement/foam interface were found to have a small effect. These findings will now be applied to larger models of whole joints.

Acknowledgements: EPSRC and DePuy International Ltd.

References: [1]: Wijayathunga et al., J. Eng Med., 2008