

The Cement-Bone Interface: A Comparative Experimental and Finite Element Study

¹Zhao, Y; ¹Jones, A C; ¹Wijayathunga V N; ¹Jin, Z M; ¹Wilcox, R K
¹Institute of Medical and Biological Engineering, University of Leeds, Leeds, UK

INTRODUCTION: In previous finite element (FE) studies of joint replacement, the bone-cement interface has been represented in a simplified form by the properties of the bone and pure bulk cement respectively. In previous studies of vertebroplasty, the augmentation region has also often been represented as pure cement, but a recent study has shown this to lead to a large overestimation in the predicted stiffness of the augmented vertebra [1]. The aim of this study was to compare different methodologies for representing the cement-bone interface using subject-specific models of a trabecular-like foam material augmented with cement. Direct comparisons were made between the model predictions and corresponding experimental tests.

METHODS: Three sets of six cylindrical specimens were cut from open cell polyurethane foam (Sawbone, Sweden). The first set was not augmented, the second was fully augmented with PMMA cement and the third was partially augmented by injecting cement into the centre of the specimen. All specimens were scanned using micro-computed tomography (Scanco μ CT80, Switzerland) and tested under axial compression.

Based on a previous convergence study [2], FE models were built with a maximum element size of 1.5 mm using the μ CT image grey-scale data. From the first two sets, factors converting the grey-scale to elastic modulus for each element of the pure sawbone and the cement-sawbone composite were determined by comparison with the compression tests. For the final set, FE models were generated by three different methods. Method I: both sawbone and cement regions were assigned single homogenous properties; Method II: the elements in the sawbone region were assigned element-specific properties based on the image grey-scale, whilst the cement region was defined with a single homogenous property; Method III: elements in both the sawbone and cement regions were assigned element-specific properties based on the greyscale using the factors determined from the first two sets.

For both Method I and II, different properties of the cement region were defined and compared. Firstly, the properties of the cement region were defined as the same as those of pure cement (2500 MPa), as has been used previously [3]. Secondly an average elastic modulus was defined based on the average greyscale value and the selected conversion factor (giving a value of 345 MPa).

To examine the relative effects of the difference in the elastic modulus of the cement and bone, two groups of models were built based on the homogenous models in Methods I. In these groups, the elastic modulus of the sawbone region and cement region were respectively increased to twice their original values. Both the predicted specimen stiffness and maximum von Mises stress were compared with the homogenous models.

RESULTS: For the partially cemented computational models, the comparison between the predicted stiffness and

that of the experimental values is shown in Figure 1 and the average absolute errors in Table 1. With the homogenous models in Methods I, increasing the elastic modulus of the sawbone region to twice of its original, increased the predicted specimen stiffness by 90%, but the maximum von Mises stress remained the same. Conversely, increasing the elastic modulus of the cement region to twice of its original, the stiffness increased by less than 1%, and the maximum von Mises stress increased by over 80%.

Method	I	I	II	II	III
Eccement (MPa)	2500	345	2500	345	varying
Error (%)	18.3	13.2	12.2	5.48	5.25

Table 1: Average absolute errors between FE-predicted and experimentally-measured stiffness

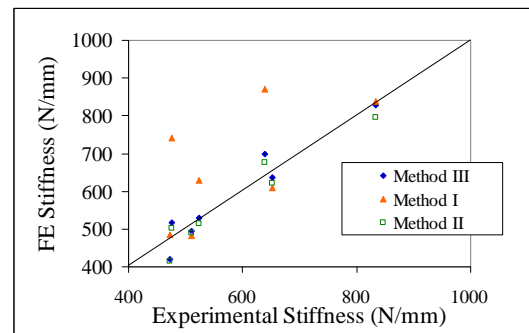


Figure 1: Agreement between FE and experimental stiffness

DISCUSSION: The results of this study showed the error in the FE model predictions using the traditional method to define the cement region were over 12%, while the grey-scale based methods reduced this error to ~5%. Good agreement was also found where a homogenous value was used for the whole cement region, but this value was based on the mean grey-scale and was considerably less than that of pure cement.

The study also demonstrated that the apparent elastic modulus is dominated by the property of the sawbone unless the cement was injected completely between upper and lower endplates. High stiffness cement would not increase the overall stiffness but only increase the maximum stress. This suggests that if a high stiffness cement were used in clinical applications, fracture within the interface region where bone and cement are interlocked is more likely than if a lower stiffness cement were used.

In conclusion, this study has indicated that the most commonly used methods of representing the cement-bone interface are likely to overestimate its stiffness and that greyscale-based methods can provide a better alternative for more accurately representing the properties of this region.

REFERENCES:

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