Strain patterns adjacent to bonded and debonded bone-implant interfaces: A holographic study of an idealised proximal femur

J. A. Simões1, J. Monteiro2, J. Chousal2, M. Vaz2, and M. Taylor3

1Department of Mechanical Engineering, University of Aveiro, Portugal. 2Department of Mechanical Engineering, University of Porto, Portugal. 3Department of Mechanical Engineering, University of Southampton, England.

Introduction
The measurement of deformation within cancellous bone is extremely difficult using conventional contact measurement techniques due to the materials highly porous structure and poor mechanical properties. An experimental set-up using speckle interferometry was developed and assessed for its applicability to measure the displacement and strain patterns of a cancellous bone substitute (commercial polyurethane HEREX® C 70.40). The cancellous bone of the proximal femur was idealised as a simple foam cube and the prosthesis as a prismatic metal tapered rod, which was inserted centrally in the foam cube. The model was sectioned longitudinally to expose the foam at the "bone-prosthesis" interface and the displacement and strain field of a bonded and debonded implant was assessed.

Materials and methods
An experimental jig was designed and manufactured to carry out the testing. For the bonded interface, the implant was glued with a very thin layer of an epoxy resin to the foam. To measure the in-plane displacements, a set-up with four directions of illumination [2], duplication of the set-up proposed by Ennos [3], was used to measure the in-plane displacement field at the surrounding “bone” due to the axial movement of the implant. Within the holographic fringe patterns each fringe represents points of an equal displacement in the direction of the sensitivity vector. An image processing system was used to calculate the phase distribution and the data were transformed to obtain the displacement and strain patterns.

Results
The displacement fields in the region of the “bone”, surrounding the bonded and debonded implants, were assessed in the axial and transverse directions of the implant. For both bonding conditions, a constant displacement was applied to the implant and it was observed that qualitatively the fringe pattern did not depend on the displacement value. Therefore, to obtain a reasonable number of fringes, a 0.1 mm displacement was applied. The fringe patterns in the axial direction of the debonded implant is shown in figure 1. Using image processing techniques with phase shift, the phase distribution was obtained in the relevant study area. As the phase is the relevant information of the fringe pattern, the displacements from the phase maps and strains were determined. Figure 2 shows the derived iso-displacement field for the axial direction of the debonded implant. Figure 3 shows the strain field obtained by differentiating the displacement field of figure 2.

Discussion and conclusions
The preliminary study hereby presented clearly showed that the experimental technique developed is suitable to obtain the strain distribution within a porous media, and therefore applicable for the examination of cancellous bone strain distributions.

In the immediate vicinity of the implant, the fringe patterns were similar to those predicted by finite element models, for both bonding conditions and for the axial and transverse displacements. The debonded implant generated much higher displacements and the points of the foam adjacent to the implant move in the transverse direction mainly due to the wedging of the implant, allowing the implant to subside inside the foam. This phenomena was not so markedly observed with the bonded implant.

The final goal of this preliminary study is to obtain detailed knowledge of the influence of interface bonding conditions on the displacement/strain patterns of the implant within the surrounding media, which will allow to speculate with more certainty on the load transfer mechanism.

References