An Approach to Characterising Femoral Neck Structural Properties Following Resurfacing

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INTRODUCTION:
Femoral head resurfacing is an increasingly common surgical procedure, which aims to preserve maximal bone stock whilst effectively acting as a hip replacement. Concerns, however, regarding possible neck fractures have instigated numerous clinical and some computational investigations in an attempt to determine its cause. It is understood that alterations in the structural properties in the femoral neck following arthroplasty, can predispose the neck to loading conditions which the neck may not handle be able to carry. Previous studies have looked at geometric and radiographic parameters in an attempt to better understand the mechanical characteristics of the femoral neck [1,2]. Other studies have used the finite element (FE) method [3,4]; however their analyses were purely based on the direct stress and strain results. This study employed the FE method to determine the typical stress and strain conditions and then used these results in combination with the non-homogeneous beam theory to investigate the structural properties of the femoral neck. Results were analysed at each slice following mapping of the properties onto a consistent hex mesh.

MATERIALS:
One cadaveric femur was CT scanned and geometry reconstructed using Amira (Mercury Computer Systems, ZIB, Berlin, Germany). A correctly sized Articular Surface Replacement component (ASR, Deux International, Leeds, UK) was positioned and this confirmed by an orthopaedic surgeon. An intact and post-operative FE model was constructed for each case using the pre-processor Patran (MSC.Patran, MSC.Software Corp., Santa Ana, CA). All geometries were meshed using 10-noded modified tetrahedral elements and mesh size ranged between 1-4mm, depending on region of interest (Figure 1). The femoral neck was carefully meshed in each case so that the element size was small enough to capture enough material definition. Material properties for the bone were obtained from the CT images based on the Hounsfield Unite (HU) values according to Carter and Hayes [5]. Peak stair-climbing loads were applied and the analyses were computed using ABAQUS/Standard (Simulia, Providence, RI, USA).

RESULTS:
In this study, the length of the neck was divided up into 10 slices. Having the material properties in a matrix-like arrangement, allowed calculations to be made on each of the 10 slices of the neck. The non-homogeneous beam theory was used to determine the mechanical response of the composite structures. Some of the variables calculated included: the centroids (and hence neutral axes), axial forces, shear forces and bending moments.

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Figure 3: Neutral axes of the intact and post-operative femoral necks

Bending moments were taken about the principal axes of each slice. The post-operative model showed greater overall bending moments moving away from the head of the femur along the neck compared to the intact model. However, at the very start (slice 1) the intact model (pink) experienced greater bending moments than the post-operative (brown) (Figure 4). This is shown by the red ellipse.

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Changes in shear and axial forces were minimal between the 2 models.

DISCUSSIONS:
Femoral neck strength depends on both geometry and density-based characteristics. Inserting an implant (stem) into the bone altered the structural quality of the neck. A greater bending moment was observed moving away from the femoral head compared to the intact, but this was contradicted in the early stages, where maximum stresses were observed close to the head. This is related to the altered load path following implantation. These behaviours would also have implications in the long-term with bone remodelling.

REFERENCES:

Figure 1: Intact and post-operative models

Figure 2: Mapped material properties of an intact and post-operative femoral neck

Figure 4: Bending Moments of the intact and post-operative femoral necks along the 10 slices (1=head end, 10= femoral shaft end)