A Combined Finite Element and Radiological Analysis of the Proximal Femur Following Hip Resurfacing Arthroplasty
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Introduction: Sectioned femoral components retrieved from failed hip resurfacing arthroplasties show resorption of proximal femoral bone or formation of a fibrous membrane at the bone cement interface, in a proportion of cases (Fig. 1)1. We hypothesize that both scenarios create a functional discontinuity zone (FDZ), which exacerbates off-loading the proximal bone and promoting resorption. Our study uses finite element modeling to examine the effects of the presence of an FDZ on bone remodeling following hip resurfacing arthroplasty. A radiographic analysis of the proximal femur following hip resurfacing was also conducted in order to draw a comparison to clinical findings.

Materials and Methods: Previously developed 3-D FE models of a natural femur and BHR were implemented with modifications for FDZ simulation2,3. The femur models were based on the geometry and material properties of a 45 year-old female donor hip with no known bone disorder (ScienceCare Anatomical, Phoenix, AZ). Non-homogeneous, isotropic, linear elastic material properties were assigned to the trabecular bone based on the donor QCT data and reported density-modulus relationships4.

The hip resurfacing FE models consisted of a 46 mm O.D. femoral component oriented at three distinct stem-shaft angles: 136° (“neutral”), 120° (“varus”) and 150° (“valgus”). The femoral head was assumed to be bonded to the cement layer, while the uncemented stem was assumed to have a frictional interface (μ=0.3). A low-modulus (2 MPa) FDZ (approx. 2mm thick) was simulated proximal to the device. Clinically relevant femoral joint (2.4×BW) and muscle loads were applied to simulate peak joint loading during gait5. The correction of femoral offset due to the changes in stem–shaft angles was not considered in this analysis, consistent with previous radiographic findings6. Interface stress was compared for the normal and simulated FDZ resurfaced femurs. Bone remodeling stimuli was determined using changes in strain energy.

A retrospective radiological analysis was simultaneously undertaken to study changes in the proximal femur following hip resurfacing arthroplasty. Radiographs of 98 hips (74 male, 24 female) with a minimum of 5 years follow up were examined (4 McMinn, 10 Cormet, 84 BHR). Measurements of the prosthesis-shaft angle, pre- and post-operative femoral head offset and femoral neck diameter at 2 and 5 years were undertaken. The results of the FE analysis were compared to the radiological findings.

Results: The presence of the simulated FDZ in the FE analysis resulted in increased proximal-medial bone resorption and slightly greater bone formation surrounding the stem (Fig. 2A). Correspondingly, device-bone interface stresses were found to decrease proximally under the loading platform and increase at the stem, particularly adjacent to the stem-head junction (Fig. 2B). The valgus BHR femur led to increased resorption, especially around the periphery of the neck and on the medial side (Fig. 3), consistent with trends from previous studies2. The radiological analysis yielded the identification of 2 groups; 22 hips (Group 1) had a mean 5.61mm (sd±2.07) reduction in neck diameter over 5 years and 76 hips (Group 2) demonstrated slow reduction in neck diameter, mean 1.13mm (sd±0.97). Neck thinning at 2 and 5 years was significantly greater for Group 1 (p<0.0001). Group 1 hips had significantly greater reduction in femoral offset (p=0.041), with greater valgus angle oriented components (p=0.09). Reduction in femoral offset was significantly associated with greater valgus orientations (p=0.0001). The Group 1 revision rate was 36.4% compared to 2.6% in Group 2 (p<0.0001).

Discussion: The FE results support the hypothesis that the presence of a FDZ decreases load transfer to the proximal bone, resulting in increased medial stress shielding and resorption. These results are consistent with the Group 1 clinical findings in which accelerated neck thinning and increased revision rates were exhibited. In order to better understand the cause of implant failures in hip resurfacing arthroplasty, additional retrieval studies are necessary.