Total Hip Replacement: Effect of Cement Mantle Thickness - An Integrated Computational Simulation and In Vitro Study

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INTRODUCTION: Cemented hip replacements are still the gold standard by which all other methods of replacements are compared. [1] However, high stresses developed in the cement mantle of reconstructed hips can lead to premature failure of the constructs. [2] There are wide variations in surgical fixation techniques among orthopaedic surgeons [3] and fixation techniques affect longevity of this study is to investigate the effect of cement mantle thickness on the stability of the acetabulum component following a total hip replacement.

METHODS: *In Vitro Tests*. Nine synthetic hemi-pelvic bones, with material properties similar to the human bone, were reconstructed with cement mantle thicknesses of 4.5mm, 3.0mm and 1.5mm, with three specimens in each group I, II and III, respectively. The same surgeon implanted all the Charnley Flanged 22.225 mm internal diameter acetabular cups to reduce variability. A CEMVAC mixing module was used to vacuum mixed the Smart Set HV bone cement from DePuy Company. A jig was designed to hold the specimens in place on an Instron 8874 bi-axial testing machine. The specimens were kept fixed at the sacro-iliac joint areas and pubic support areas. They were dynamically loaded for 720,000 cycles in 4 batches of 180,000 cycles at a frequency of 5 Hz to simulate compressive forces acting the hip joint during the gait cycle with a maximum of 2743N. Flexion-extension movement was also simulated. The displacements of the acetabular cups and the hemi pelvic bones were measured, using linear variable displacement transducers (LVDTs) from Solatron Metrology. The relative displacement of the acetabular cups were calculated by subtracting the recorded displacement of the cups from the displacement recorded for the hemi pelvis bones.

Computational Simulations. Mimics (V9 from Materialise, Belgium) was used to create anatomically accurate three-dimensional (3D) model of a hemi pelvis, with a 52mm diameter acetabulum, using CT-Scan data obtained from the Visible Human data set. The 3D model of the hemi-pelvis was exported to I-Deas 11.0 finite element analysis package, where the anatomically accurate finite element (FE) model of the reconstructed hemi pelvis was created with cement mantles of 1, 2, 3 and 4 mm thick. Fixing and loading conditions, corresponding to the in vitro tests, were applied. Finite element analyses were carried out to investigate the stresses developed in the reconstructed hemi pelvis.

RESULTS: The results of the average relative displacement of the cups at the anterior-superior region for the three different cement mantle thicknesses after 720,000 cycles show that there was an increase of 17.2% in mean average relative displacement with a decrease in the cement mantle thickness of 1.5 mm from Group I to II. An increase as high as 36.7% was recorded for a decrease of 3 mm in the cement mantle thickness from Group I to III.

FE results show that a decrease in cement mantle thickness from 4mm to 3mm, 2 mm and 1mm increased tensile stress in the cement from 7.26 MPa by 5.4 %, 12.9% and 33.7%, respectively.

DISCUSSION & CONCLUSIONS: The in vitro and computer simulation studies show that increasing the cement mantle thickness increases the mechanical stability of acetabular cup fixations. The use of too much cement could thermally damage osseous tissues. Hence, a reasonably thick cement mantle, of up to 4mm, would result in improved mechanical stability and reduced risk of tissue necrosis.

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