Introduction: A number of densitometry studies have reported dramatic density losses in the acetabular region after uncemented Total Hip Arthroplasty (THA)[1,2]. However, the mechanical implication of such loss is not yet known. This study aims to perform a mechanical analysis with patient specific Finite Element (FE) models to find out how the stress distribution affects the Bone Mineral Density (BMD) changes after uncemented THA.

Materials and Methods: An existing patient CT dataset collected for a quantitative CT (qCT) study was used. Patients were scanned 10 days, 1 year and 3 years after the surgery. Total six qCT slices were taken from the acetabular region: 1) three above the cup; 2) three at the level of the cup. BMD changes at each slice had been analyzed in a previous study[3]. Patient-specific FE models of two patients were generated with a previously validated FE mesh generation method[4]. Since CT scans covered only the acetabulum region we used a method[5] where a sparse patient data set uses supplementary data from another data set (Visible Human) to generate a full FE model of the pelvis. Supplementary bone data from the Visible Human data sets were calibrated to be in the same range as the patient data set. Five materials were incorporated into the model – Titanium cup (110 GPa), polyethylene liner (1GPa), subchondral (6.9GPa) cortical (17GPa) trabecular bones, which was assumed to have position dependent modulus values. Using the relationship given in [6], trabecular modulus values were calculated from CT scans. Cortical shell thickness was also measured from CT scans using the method developed in [4]. The contact between the metal cup and the acetabulum was modeled using a contact mechanics penalty method involving Coulomb friction (μ=0.3). Boundary and loading conditions included the hip joint force and the forces of 21 muscles attached to the pelvic bone at the single leg support phase of a gait cycle[7]. Mechanical simulations were run and tensile and compressive components of principal stresses were calculated for each slice at all three follow-ups and compared with the BMD changes reported in [3].

Results: In general, both compressive and tensile principal stresses decreased after uncemented THA and the pattern of stress decrease followed the BMD decrease pattern. Therefore, stress decreases from the three slices above the cup (-22%) were much smaller than stress decreases from the three slices at the level of the cup (-46%).

Two different types of stress distribution plots were generated for analysis. Firstly the surface stress pattern was plotted on the pelvic mesh (Figure 1). Then internal stresses were plotted for slice by slice comparison as done in the densitometry study[3] (Figure 2). The overall surface stress pattern showed that tensile stress decreased more dramatically than compressive stress as the characteristic pattern of the overall stress distribution changed for tensile stress while the compressive stress distribution pattern was maintained (Figure 1). Interestingly, there is a tensile stress increase in the superior dome of the prosthesis, which matches well with the densitometry finding. Internal stress pattern also confirmed this finding as slices superior to the cup did not show much change in stress distribution after surgery. Moreover, the densitometry study revealed that areas dorsal to the prosthesis lost more bone density than areas ventral to the prosthesis[3]. Internal stress distribution plots showed that tensile stresses in the dorsal areas decreased over time while ventral areas did not experience such decrease (Figure 2). This pattern was not observed in the internal stress distribution of compressive stresses. Overall, tensile stress seemed to follow more closely to the BMD change pattern.

Discussion: This study compared tensile and compressive stresses with the BMD changes after THA. Our results showed that both tensile and compressive stresses generally follow the BMD changes as they all decreased. However, tensile stress seemed to have a closer correlation with the BMD than compressive stress. The fact that the major characteristics of the overall stress distribution pattern was maintained for compressive stresses while that of tensile stress did not suggests that tensile stress might play a bigger role in the BMD pattern changes after uncemented THA. However, this is a result from two patients and caution is needed when interpreting this result. More patient datasets are being processed to test this hypothesis. Findings from this study can explain phenomena of retroacetabular osteolysis, late migration and implant failure of press-fit cups observed in long-term clinical studies.

References:
2. Wright JM et al. JBJS American 2001;83:529-536.