INTRODUCTION

The distribution of weight bearing area within the acetabulum is of importance in addressing trauma to the acetabulum and understanding load distribution transmission through the hip joint. The distribution of bone density and loading in the acetabulum is also important in the design of total hip replacements, the treatment of hip joint deformities and in better understanding causes of osteoarthritis. It is well known that acetabular fractures of the posterior wall carry higher risk of early arthritic changes. Bone adapts to the load that it experiences, with highly loaded areas exhibiting increased density bone and low load areas resorbing bone; as such, bone density can indicate common loading patterns experienced. Bone density data can be extracted from CT scans and visualized on acetabular surfaces, creating bone density maps of the acetabulum. The objective of this study was to characterize distributions of normal acetabular bone density in order to improve understanding of the relative importance of different regions within the acetabulum with respect to load bearing.

MATERIALS AND METHODS

A population of 22 subjects (16 males and 6 females), mean age 70.6 years, was used for this investigation. All CT scans used were digital and obtained from individuals being evaluated for non-orthopaedic pathologies at our institution. Based on CT scan screening, only those without joint replacements, fractures, and osteoarthritus were included in the analysis (Institutional Ethics Board approval was granted).

Bone density distribution maps were generated within AmiraDEV4.1 image analysis software using custom written plugins (Visage Imaging, Carlsbad, USA). Acetabular cup surfaces were semi-automatically segmented from the reconstructed CT volumes with an atlas based approach. Atlas data sets, consisting of CT scan data and a previously obtained segmentation of the femoral head were aligned to the patient scan with an affine registration followed by a morphing with level set motion deformable registration. Femoral head segmentations were further refined by level set segmentation, expanding the segmentation from the femoral head to the acetabular cup surface. The acetabular cup was then expanded 2.5mm into the acetabular bone, and surface bone densities were calculated as the average bone density within ±2.5mm. (Figure 1)

The distribution maps were analyzed using zones to spatially classify areas of high and low bone density in a healthy population. The density maps were aligned using the acetabular rim plane that was landmarked on successive axial cuts of the CT scans. The acetabular cups were then aligned by rotating the cups, such that a 90° abduction angle and a 0° anteverision angle were achieved. The grid used was intended to encompass the differences along the anterior-posterior and superior-inferior axes (Figure 2). The map was further subdivided into radial thirds of the average rim radius.

The correspondence of left and right density maps was investigated by comparing the average bone density in corresponding zones. These average values were further compared between subjects to find average zone values across the population.

RESULTS

This investigation of 22 subjects showed the areas of highest average bone density to be the superior and posterior walls of the acetabulum. These areas, corresponding to regions 8, 9, and 12 (Figure 3), exhibited significantly greater density in all subjects as compared to other regions of the acetabulum (P<0.01). The highest average bone density values were located in region 12 for both sides and were found to be 443.5 HU (Hounsfield Units) for the left side and 450.4 HU for the right side.

DISCUSSION

The location of the zones with the highest average bone density agrees with cadaveric studies of the maximum contact stress in the acetabulum (zones 9 and 12). [1,2] The bone density intuitively seems to correlate with highly loaded areas, as the horseshoe geometry of the acetabulum increases loading to areas around the edge. It may explain why trauma to these areas carries a higher risk for early arthritic changes. High bone densities were also found around the roof of the acetabulum aligning with the femoral mechanical axis during standing, likely caused by large loads imparted by the femur.

Previous studies have investigated load and bone density distribution around the acetabulum using a limited number of cadaveric specimens. Small cadaveric studies may not be entirely indicative of the normal adult population as the specimens may be old, pathologic and of a small number. This study has the advantage of a relatively large number of samples and of a healthy population.

Overall, this investigation has demonstrated the potential for using image analysis to gain insight into hip joint loading / mechanics. The analysis of a healthy population has shown that large differences in bone density exist around the acetabulum that may be important to consider clinically during surgical interventions.

REFERENCES