INTRODUCTION

Previous investigations of loads transmitted through the hip joint have focused on using instrumented prostheses to measure in-vitro and in-vivo force distribution. Such studies are important for understanding native mechanics of the joint, but due to the requirement for substantial hardware to be implanted, lack in their ability to be applied to a more general population.

Analysis of the function of bone through examination of its structure is made possible by the structure-function relationship developed by Wolff. As such, determination of bone density distribution can be used to infer the average loading distribution on the femoral head. Imaging modalities such as computed tomography (CT), can be used to visualize the structure of femoral head subchondral bone, which allows for in vivo quantifications of joint mechanics without the need for implanted hardware.

This study aims to characterize the native femoral head by quantifying the distribution of subchondral bone density across the articular surface. We hypothesize that a non-uniform distribution of bone density will be observed, with correlation between left and right sides for a given patient.

METHODS

A cohort of 30 subjects (14 males and 16 females) with mean age 67.8 years was used for this investigation. All CT scans (GE, 2.5 mm slices spaces 1.25 mm apart) 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 osteoarthritis were included in the analysis (IRB approved).

Bone density distribution maps were created within AmiraDEV 5.2.2 (Visage Imaging, Carlsbad, USA) image analysis software using in-house scripted code. Femoral head surfaces were created through semi-automatic segmentation of reconstructed CT volumes using a thresholding technique. The surfaces were used to map bone density by shrinking them 2.5mm into the subchondral bone and averaging the grey values (linearly related to bone density, measured in Houndsfield Units) within 5mm of the articular surface. Density maps were then aligned to a reference axis with the center of the head at the origin, the femoral mechanical axis (FMA) aligned with the vertical, and the posterior condylar axis (PCA) subsequently aligned with the horizontal.

The regions were created by first dividing the density maps into three concentric rings at increments of 30° from the horizontal. Each ring was split into four quadrants, along the anterior-posterior and medial-lateral axes, resulting in twelve regions consistently defined for each femoral head (Figure 1). The average density of bone within each region was then calculated using histogram analysis.

The average bone density values found for each region were compared using repeated measures ANOVA analysis. Post-hoc testing with Bonferroni correction was used to determine significant differences between regions. Correlations between left and right sides were quantified using Pearson’s correlation coefficients. All statistical analysis was performed using PASW 18 (SPSS Inc., Chicago, USA).

RESULTS

Femoral head bone density maps were successfully created bilaterally for 30 patients. Regions 1 and 4 on the right side were found to have significantly higher densities compared to other regions (p=0.000, p=0.027) (Figure 2). Regions 1 and 4 on the left side were significantly more dense than all except region 5, which was significantly lower than region 1 (p=0.000) but not region 4 (p=0.595). Side-to-side differences in measured bone density were seen for region 3 (p=0.047) and region 11 (p=0.025) only. Significant side-to-side correlations were found for all regions (r=0.90 to r=0.40), with very strong correlations for the highest density regions (r=0.85 for region 1, r=0.84 for region 4).

DISCUSSION

The locations of highest bone density correspond with principal contact areas found in previous investigations of loading in the human hip joint [1]. Also, the regions of highest bone density corresponded qualitatively with the direction of the principal compressive trabecular bone group (Figure 3) shown to support the highest compressive load through the femoral head.

The regions of the femoral head found to have highest average bone density, correspond well with high density regions found previously for the native acetabulum [2]. Although the region definitions are based on different coordinate systems exclusive to each bone, in the standing position regions 1, 4, and 5 align with the high density superior and posterior walls of the acetabulum.

The high correlation found between left and right sides for all regions indicates that density on one side can predict that of the other. Thus, this tool may be used to detect small differences in bone density caused by unilateral hip pathologies, such as osteonecrosis or osteoarthritis of the femoral head, which may allow for a diagnosis prior to the presentation of clinical symptoms. This technique is limited however, as with many other imaging methods, in situations where metal hardware is present.

REFERENCES
