INTRODUCTION: Two-dimensional radiographic measures of acetabular coverage remain the gold standard for making diagnoses of hip dysplasia and femoroacetabular impingement (FAI) [1-4]. However, radiographic measurements are limited by pelvic orientation and image quality, thus making them somewhat subjective. These measures may not be a reliable way to detect the degree and spatial distribution of over-coverage or deficiency in subtle cases of acetabular retroversion [5,6]. Surgeons, radiologists, and patients may benefit from a reliable and objective method to easily measure acetabular coverage by anatomical region. A rigorous definition of coverage would elucidate the degree of variation in regional coverage in retroverted patients when compared to normal hips, and facilitate easier pre-surgical planning.

The aims of this study were to develop an objective method for measuring acetabular coverage using subject-specific 3D reconstructions and to quantify population differences in regional coverage between retroverted dysplastic and normal hips.

METHODS: Volumetric multi-detector CT scans of 20 asymptomatic normal (8 female, 12 male, mean age = 44 yrs, mean weight = 68 kg) and 13 symptomatic retroverted (2 female, 11 male, mean age = 23 yrs, mean weight = 77 kg) hips were acquired under IRB approval (28721, 10983). The image data were reconstructed into 3D surfaces representing femoral and pelvic cortical bone using commercial software (AMIRA V5.2.1, Visage Imaging, San Diego, CA). A cubic spline was fit to the rim of the acetabulum and projected to the nearest points on the surface of the femoral head to create a line of acetabular coverage (Fig. 1a). The femur head-neck junction was defined by first creating a contour map of principal curvatures across the entire femur [7], and then connecting nodal points of inflection (curvature = 0) circumferentially around the head (Fig. 1a). A best fit plane was matched to the inflection points and the head was cut along this plane. Using the coverage line, the surface area covered by the acetabulum was calculated as a percent of the entire head. Next, a plane was created to bisect the head based on 3 points: the geometric center of the head when fit to a sphere, the center of the narrowest cross-section of the neck, and the circumferential center of the femoral shaft. A second plane was created perpendicular to the first, and the head was divided into four anatomical regions: anterior-lateral (AL), anterior-medial (AM), posterior-lateral (PL), and posterior-medial (PM) (Fig. 1b). Percent coverage of each region was determined and significant inter-population differences (p<0.05) were tested using Mann-Whitney tests.

RESULTS: Control subjects had average total head coverage of 56.9 ± 4.8%, which was significantly greater than the 49.7 ± 3.7% coverage in retroverted patients. Anterior (AM + AL) coverage in the controls averaged 36.4 ± 8.0%. Anterior coverage in retroverted hips was greater (39.0 ± 9.4%), but not significantly. In contrast, the posterior half of control subjects was 77.6 ± 7.7% covered, while patients had significantly less posterior coverage at 61.0 ± 4.9%. Coverage analyses by quadrant revealed significant differences between the groups in both PL and PM, but not AL or AM (Fig. 2).

DISCUSSION: The objective of this study was to compare femoral head coverage in retroverted dysplastic patients and controls by region. This was done with a method that allowed little subjectivity in head selection or coverage area distinction.

Reynolds et al. found no qualitative difference in overall coverage of the femoral head between normal and retroverted groups [2]. The current study did find the deficiency in total head coverage in patients to be statistically significant. The difference may arise from the fact that the control group in the Reynolds study consisted of patients who had originally been referred for the investigation of hip disorders, while the normal and patient groups in the present study were distinctly separate. Regardless, differences in total coverage that are statistically significant may not be clinically significant as deficiency in retroverted patients is recognized as a regional problem.

The relationship between the degree of anterior over-coverage and impingement is unclear. The patients in this study did not have significantly more anterior coverage than the controls, yet each tested positive for pain in a clinical impingement test and later underwent a peri-acetabular osteotomy (PAO). This suggests that only subtle differences in acetabular over-coverage may be enough to cause impingement. Our results also suggest that lack of coverage in the posterior region of retroverted patients may be more severe than anterior over-coverage. The PAO procedure, in the setting of a retroverted patient, seeks to not only eliminate anterior lateral impingement, but to also provide better posterior coverage. While an increase in load-bearing surface area after PAO has been found in traditional dysplastic patients [8], anterior-to-posterior rotation of the acetabulum in retroverted patients may not significantly improve coverage. Future work will couple mechanical findings from subject-specific FE results to ascertain whether or not deficiency in the posterior region is cause for altered mechanics.

A potential limitation of this study is that the models were created from CT scans acquired in the supine position. The argument has been made that 2D hip radiographs are more appropriately done standing, as this replicates physiological orientation [1]. Thus the pelvis is tilted more anterior when standing, which may exacerbate the degree of posterior deficiency we detected. However, the degree of tilt was likely similar for controls and patients. Also, using a 3D model it would be possible to reorient the joint to any position for purposes of evaluating coverage and likelihood of impingement during different activities.

Current surgical pre-operative planning for retroverted patients is based on 2D radiographic measures and clinical exams [9]. This study has shown the regional differences in acetabular coverage can be detected with a simple, yet objective 3D method. In the future, we will expand our sample body and determine if correlations exist between common 2D measures and 3D coverage. This would determine the power of radiographic measures for predicting regional coverage.

ACKNOWLEDGEMENTS: NIH #R01AR053344, University of Utah Sherman Coleman Resident Research Grant.