Quantifying differences in femoral head and neck asphericity in the common hip conditions of femoroacetabular impingement (FAI) and hip dysplasia versus controls using radial 3DCT imaging and volumetric segmentation

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INTRODUCTION

Hip dysplasia and FAI are common conditions in adults presenting with hip pain. Symptomatic pain is generally located in the anterior hip and/or groin and may radiate laterally or posteriorly into the buttocks along with sensation of the hip "locking." Patients with both conditions have characteristic developmental bony abnormalities, and eventually develop osteoarthritis in the affected hip. Imaging of the hip can demonstrate "asphericity" or "bump" of the femoral head associated with both FAI and dysplasia. This femoral head abnormality has been historically quantified using alpha angles on both Xrays and 3D CT scans. However, alpha angles have been shown to be an unreliable measure of symptomatic pain. Abnormal alpha angles, >55°, are frequently observed in asymptomatic patients, and patients with significant pain and bony abnormalities may exhibit normal alpha angles. The "bump" at the femoral head and neck junction has not been systematically assessed or correlated with the symptoms of patients as has been the alpha angle. This study was aimed to measure the traditional alpha angles on radial 3D CTs and segmented bump volumes in patients with FAI and hip dysplasia. We hypothesized that the bump volume would be a more reliable measure separating these conditions from each other and from the controls. Quantifying differences among these three groups shall aid in understanding the disease mechanisms of impingement and instability and may aid in surgical planning of such patients.

Figure 1: Alpha angle measurements in FAI surgical case. Alpha 12,1,2,and 3 represent the respective O'clock positions.

Methods and Results:

Subjects: The patients were 18-50 years old, referred by specialized orthopedic hip surgeons. Patients had pre-operative 3D CT evaluation of the pelvis. CT imaging was performed using an isotropic voxel of 0.625mm from the level of L5 vertebra to the lesser trochanters. Pelvis, including both hips, was imaged in all cases. Detailed chart review established side of pathology, patient symptoms, and basic demographic data. Final diagnosis of FAI or dysplasia was established by the surgeon in all cases and was recorded in the patients' charts.

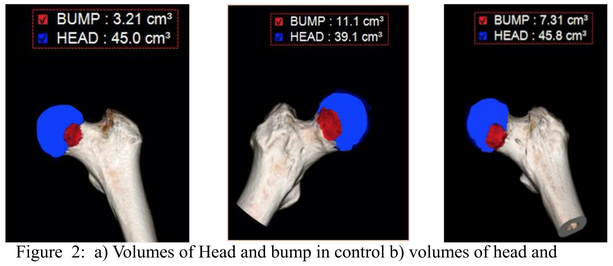

Figure 2: a) Volumes of Head and bump in control b) volumes of head and anterolateral bump in FAI c) Volumes of Head and inferolateral bump in dysplasia.

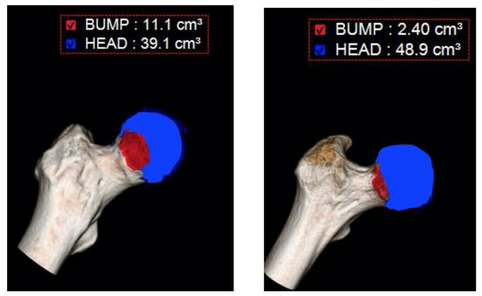

Figure 3: a) Pathologic hip in FAI showing the volumes of head and bump b) contralateral normal hip in patient with FAI showing volumes of head and bump

Image evaluation: Two readers independently performed all the measurements after performing 6 scans together for training. The case-control data was anonymized, and the readers were blinded to the patients' history and laterality of symptoms. The Alpha angles were measured on radial 3DCT reconstructions. A "clock face nomenclature" was used for mapping the femoral head-neck junction with the anterior location as 3 o'clock and the superior location as 12 o'clock. The alpha angle was determined by a line through the center of the femoral neck to the center of a best fit circle, and a line connecting the center of the circle to the point where the femoral head exited the boundary of the circle. The clock face was rotated from 12, to 1, to 2 and finally to 3 O'clock, on the axial view of the CT. Four long axis images, one for each hour, were obtained. It took an average of 20 minutes to obtain alpha angle measurements. Quantification of the femoral head-neck junctional "bump" and femoral head volumes were obtained utilizing the 'region grow' segmentation technique. First, the free region of interest semi-automated tool was employed to remove the rest of the pelvis and acetabulum from the femur. The femoral head was carefully isolated using the 'region grow' tool and assigned a unique density based color region, avoiding the adjacent femoral neck. The volume tool was used to calculate the volumes of the head and bump. It took an average of 10 minutes to obtain head and bump segmentations and calculation of volumes.

Statistical analysis: Subjects were divided into three groups: 1. Control (both hips normal); 2. Dysplasia; and 3. FAI. Control subject hips were compared to hips of Dysplasia or FAI patients (inter-patient comparison). Abnormal hips were compared to their contralateral hip if the abnormality was unilateral (intra-patient comparison). P values less than 0.05 were considered statistically significant. There were 25 cases of FAI, 16 cases of dysplasia, and 38 controls. Subjects with FAI and dysplasia were younger on average. There was no significant difference in mean age between FAI and dysplasia. No significant difference in distribution of sex was found among controls and cases.

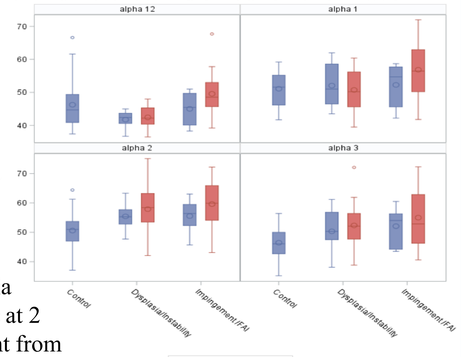

Figure 4 Bar graphs showing the inter-patient differences. When comparing cases to the controls, dysplasia hips exhibited significantly higher alpha angles at 2 and 3 o'clock (p=0.002 and 0.023).

Inter-patient comparison: Dysplasia hips exhibited significantly higher alpha angles at 2 and 3 o'clock and higher bump/head ratio. The contralateral normal hips of dysplasia patients showed higher alpha angle at 2 o'clock but not significantly different from control subjects. Among patients with FAI, the abnormal hips exhibited significantly higher alpha angles at 1, 2, and 3 o'clock and larger bump volume and higher bump/head ratio. The bump volume and bump/head ratio were also higher for the contralateral normal hips of FAI patients than the control subjects on average. FAI hips also showed significantly higher alpha angles at 12 and 1 o'clock than the hips of dysplasia patients. Bump volume and bump/head ratios were significantly larger in FAI hips than the dysplasia hips. The contralateral normal hip of dysplasia patients had significantly lower bump volume and bump/head ratio than hips of FAI patients.

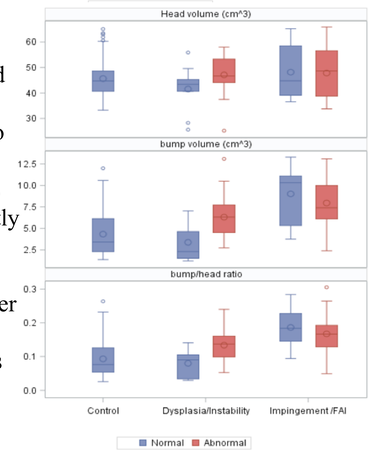

Figure. 5- Bar graphs showing the inter-patient differences: When comparing cases to the controls, dysplasia hips exhibited significantly higher bump/head ratio (p=0.029).

Intra-patient comparison: Statistical difference was found in bump volume and bump/head ratio between abnormal hip and contralateral normal hip in Dysplasia patients. Contralateral normal hips of dysplasia patients also showed higher alpha angle at 2 o'clock but not significantly different from control hips. Among patients with FAI, the abnormal hips exhibited significantly higher alpha angles at 1, 2, and 3 o'clock. The alpha angles at 1, 2 and 3 o'clock were also higher for contralateral asymptomatic hips of FAI patients but were not statistically different from control hips. Among patients with FAI, the abnormal hips exhibited larger bump volume and higher bump/head ratio. The bump volume and bump/head ratio were also higher for contralateral normal hips of FAI patients than the control subjects on average.

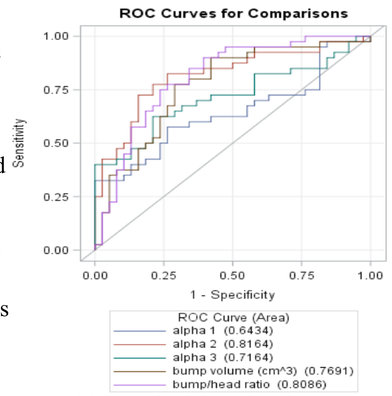

Figure. 6: ROC curves for alpha angle and segmented femoral bump and head measurements cases versus controls.

CONCLUSION

FAI and hip dysplasia are pathologic conditions typically diagnosed by a combination of patient history, physical exam findings, and CT or MRI. In FAI, radiographic and cross-sectional imaging assessment using alpha angle measurements is time consuming and has been shown to be unreliable. This was again confirmed in our study. Femoral head asphericity is not uncommon in hip dysplasia as shown in this and other studies. However, this study is unique in that we compared both types of common adult hip conditions and detected differences in the size of incongruency of head and neck junction as well as its location. In addition, FAI bumps were commonly bilateral, and the bump extent was different than the controls in both symptomatic and asymptomatic sides. This finding expands our understanding of the disease and has implications in the future course of the disease, since consequent labral and cartilage pathology can thus result bilaterally, predisposing to osteoarthrosis. The differences in bump locations may also have surgical planning implications.

To summarize, this study expands the understanding of developmental femoral head anatomic alterations and highlights the value of 3DCT volumetrics in FAI and Dysplasia by quantifying the femoral head and neck junction anatomic differences with a segmentation measurement method that is easier, faster and more reliable than the commonly used radial CT alpha angles.

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