Femoroacetabular Impingement: A Three-Dimensional Morphological Assessment

INTRODUCTION: Femoroacetabular impingement (FAI) may be the primary etiology of idiopathic hip osteoarthritis (OA) [1]. Cam FAI is characterized by a non-spherical head that shears itself into the socket causing damage to the labrum and adjacent cartilage. It can be difficult to diagnose FAI using plain film radiographs since the subtlest deformities are often missed. Further, it is not uncommon for unrelated procedures to be performed on misdiagnosed patients [2,3]. Currently, cam FAI is corrected by removing abnormal bone without a-priori knowledge of the spatial location and magnitude of the deformity. Improved methods that incorporate 3D hip morphology to locate deformity could clarify the best surgical approach. The objectives of this study were to develop a preoperative 3D modeling protocol for cam FAI patients and to statistically compare femoral head morphologies between cam patients and normal controls.

METHODS: The entire pelvis and proximal femurs of ten patients (9 male, 1 female, 6 right, 4 left) aged 21-38 (28.6±9.4 years) with suspected cam FAI were scanned using CT arthrography (IRB #10983). Approximately 20 ml of a solution containing lidocaine and Omnipaque (2:1 ratio) was injected into the hip capsule to delineate cartilage layers. Patients were scanned with a Siemans Somatom 64 Scanner (120 kVp, CARE Dose=100-400 mAs, 512 x 512 matrix, FOV=350 mm, axial resolution=1.0 mm). Ten cadaver femurs were dissected free of soft tissue with the exception of cartilage and scanned with a GE High Speed CTI helical scanner (100 kVp, 100 mAs, pitch=1.0, 512 x 512 matrix, FOV=160 mm, axial resolution=1.0 mm). All cadaver data were analyzed with the Amira 4.1 software. A baseline mask was defined to threshold the femoral cortical bone using pixel intensities shown to result in accurate bone segmentations [4]. The baseline mask was manually segmented to define bone in regions of poor contrast as described previously [4]. The resulting mesh was triangulated into a polygonal surface. Coordinates of only those nodes residing at the cartilage/bone interface of each femoral head were fit to spheres and rotational conchoids [5] using a least squares regression. When compared to spheres, rotational conchoids have been shown to better describe the geometry of the femoral head [5]. An objective function [6], which was based on the root mean squared distance native nodes have to relocate to conform to the best fit spheres/conchoids, was used to quantify fitting error.

Fringe plots detailing the spatial distribution and magnitude of the native node translations required to fit to ideal geometry were made for each patient. Coronal and sagittal planes were defined using the geometric center of the femoral head, the center of the neck, and center of the proximal diaphysis. The planes were used to divide the femoral head into the following anatomical regions: anteromedial, anterolateral, posteromedial, posteroslateral. A Holm’s controlled Wilcoxin signed rank test (matched pairs) was used to assess regional differences in deviation from a sphere within and between groups. For this test, only positive deviation values were used (i.e. abnormalities outside the best-fit sphere radius) since it was of primary interest to compare the amount of bone that should be removed during surgery between cam patients and normal controls. The Wilcoxin test with matched pairs was also used to compare values of the objective function (sphere, conchoid) and maximum deviation (sphere) between groups (p=0.05).

RESULTS: Values of the objective function for the conchoid and sphere were significantly higher for cam FAI patients compared to normal controls (Fig. 1). The conchoid provided a fit that was significantly better than the sphere for both groups (Fig. 1) (p=0.039, p=0.038 for FAI and control, respectively). Maximum deviation from a sphere for the FAI patients was also significantly higher (Fig. 1). The location of maximum deviation for FAI patients was predominately confined to the anterior region (anteromedial n=3, anterolateral n=5, posteromedial n=2, posteroslateral n=1), but was strictly confined to the anterolateral (n=3) and posteroslateral (n=7) regions for normal controls. Fringe plots qualitatively demonstrated differences in deviation from a perfect sphere between cam patients and controls and indicated that the deviation for FAI patients occurred along the periphery of the head (Fig. 2). Cam hips had significantly higher deviations from a best-fit sphere in all anatomical regions compared to controls (Fig. 3) but there were no significant differences between regions within groups.

DISCUSSION: The results confirm findings from radiographic studies [e.g. 7] that indicate joints with cam FAI are morphologically abnormal compared to normal hips. However, unlike measurements from radiographs, 3D models allow for visualization of the spatially varying magnitude of the deformity. Although sub-millimeter values for the objective value indicated that both cam and normal hips were closely approximated by ideal geometry overall, an order of magnitude difference was found between groups. Our fitting errors and conclusion that a conchoid provided a better fit compared to a sphere are in agreement with prior work [5].

Previous work [6] has demonstrated that even minor deviations from ideal geometry result in drastic changes to cartilage contact pressures. Therefore, a hip with slightly abnormal geometry may be prone to develop early OA due to increased mechanical demand. Because cam hips had significantly larger deviations than normal controls over all regions, use of radiographic measurements of the anterior and lateral regions alone may not fully describe the extent of deformity, and surgical correction in locations other than these may be indicated. To this end, the approach that was used in this study to quantify FAI pathology may be applied to assist with the diagnosis and pre operative surgical planning for patients with suspected cam FAI.

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