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Correlations between the alpha angle and femoral head asphericity: Implications and recommendations for the diagnosis of cam femoroacetabular impingement

Michael D. Harris[a,1], Ashley L. Kapron[a,1], Christopher L. Peters[b,1], Andrew E. Anderson[c,*]

[a] Department of Orthopaedics, Department of Bioengineering, University of Utah, 590 Wakara Way A-100, Salt Lake City, UT 84108, USA
[b] Department of Orthopaedics, 590 Wakara Way A-100, Salt Lake City, UT 84108, USA
[c] Department of Orthopaedics, Department of Bioengineering, Department of Physical Therapy, Scientific Computing and Imaging Institute, University of Utah, 590 Wakara Way A-100, Salt Lake City, UT 84108, USA

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ABSTRACT

Objective: To determine the strength of common radiographic and radial CT views for measuring true femoral head asphericity.

Patients and methods: In 15 patients with cam femoroacetabular impingement (FAI) and 15 controls, alpha angles were measured by two observers using radial CT (0°, 30°, 60°, 90°) and digitally reconstructed radiographs (DRRs) for the: anterior–posterior (AP), standing frog-leg lateral, 45° Dunn with neutral rotation, 45° Dunn with 40° external rotation, and cross-table lateral views. A DRR validation study was performed. Alpha angles were compared between groups. Maximum deviation from a sphere of each subject was obtained from a previous study. Alpha angles from each view were correlated with maximum deviation.

Results: There were no significant differences between alpha angles measured on radiographs and the corresponding DRRs ($p = 0.72$). Alpha angles were significantly greater in patients for all views ($p \leq 0.002$). Alpha angles from the 45° Dunn with 40° external rotation, cross-table lateral, and 60° radial views had the strongest correlations with maximum deviation ($r = 0.831$; $r = 0.823$; $r = 0.808$, respectively). The AP view had the weakest correlation ($r = 0.358$).

Conclusion: DRRs were a validated means to simulate hip radiographs. The 45° Dunn with 40° external rotation, cross-table lateral, and 60° radial views best visualized femoral asphericity. Although commonly used, the AP view did not visualize cam deformities well. Overall, the magnitude of the alpha angle may not be indicative of the size of the deformity. Thus, 3D reconstructions and measurements of asphericity could improve the diagnosis of cam FAI.

1. Introduction

Cam-type femoroacetabular impingement (FAI) has been implicated as a cause of chondrolabral damage, hip osteoarthritis (OA), and musculoskeletal pain in young adults [1–3]. Cam FAI is characterized by an aspherical femoral head and/or insufficient femoral head-neck offset [4,5]. Identifying the degree of femoral head asphericity is important as the underlying goal of surgery to correct cam FAI is to restore a more normal, spherical morphology to the femoral head.

The alpha angle is a two-dimensional (2D) radiographic measure of femoral head asphericity that is commonly used to diagnose cam FAI [6–8]. Although first proposed by Notzli et al. for only an oblique axial view of the femur, use of the alpha angle has been extended to several radiographic projections and radial computed tomography (CT) or magnetic resonance (MR) views [7,9–14]. Unfortunately, alpha angle measurements can vary between views of the same femur [10,15,16]. Consequently, the ideal view to diagnose cam FAI remains unknown [15,17].

One approach to identify the optimal view in which to measure the alpha angle has been to quantify observer repeatability. However, reports of repeatability have not been consistent and repeatability is not necessarily a measure of effectiveness

* Corresponding author. Tel.: +1 801 587 5208; fax: +1 801 587 5211.
E-mail addresses: michael.harris@utah.edu (M.D. Harris), ashley.kapron@utah.edu (A.L. Kapron), chris.peters@hsc.utah.edu (C.L. Peters), andrew.anderson@hsc.utah.edu, andy.anderson@utah.edu (A.E. Anderson).
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[18,19]. Another approach has been to correlate alpha angles from standard radiographic views to oblique axial or radial MRI/CT views [12,14,15,17]. Still, alpha angle measurements from radial views are not generated automatically, and thus do not provide a true reference standard. In addition, radial views do not consider the geometry of the entire femoral head. Alternatively, subject-specific 3D reconstructions of femur morphology, generated from volumetric CT or MR images, can be used to visualize the anatomy of the entire femoral head. By fitting the 3D reconstruction to a sphere, one can quantify the size of a deformity as maximum deviation from the sphere, herein referred to as 'true femoral head asphericity' [20,21].

Alpha angles from radiographs and radial views will continue to be used in the diagnosis of cam FAI, but the strength of each projection for quantifying true femoral head asphericity has yet to be quantified. The objective of this study was to correlate 3D model-based measurements of maximum deviation from a sphere of the femoral head (obtained in our previous study [21]) to alpha angles measured on five radiographic and four radial CT views. For the five radiographic views, digitally reconstructed radiographs (DRRs) were created from existing CT image stacks, and were used in lieu of traditional plain films. In doing so, bias in alpha angle measurements from the five radiographic projections caused by inconsistencies in inter-subject positioning was eliminated as was unnecessary radiation exposure beyond that of the original CT scan (a standard of care in our clinic). A validation study was conducted to demonstrate the suitability of DRRs as surrogates for traditional films prior to the principal study (see Appendix).

2. Patients and methods

2.1. Subject selection

Images of the pelvis and proximal femur were retrospectively acquired from 15 patients with cam FAI who had received a CT arthrogram as part of a previous study (IRB # 10983, 56086) [21]. All patients had presented with hip and groin pain, had radiographic evidence of cam FAI and tested positive for impingement during clinical examination. Patients received or were scheduled for femoral osteochondroplasty and treatment of chondrolabral injury. Three patients were treated for mixed FAI. A set of 15 control femurs was selected from an available database of cadavers (IRB #56086). Cadaveric femurs available for this study had been disarticulated from the pelvis. All musculoskeletal soft-tissue with the exception of articular cartilage was removed from each specimen. Cartilage was visually screened for degenerative changes consistent with OA. Next, the CT images were inspected for bony deformities and sclerotic changes consistent with OA and/or cam FAI. Of the remaining database, 15 cadaver specimens and associated CT images that best matched the age, weight, height, and body mass index (BMI) of the cam FAI patients were selected; none of the specimens were paired. All human studies were carried out in accordance with those policies and procedures detailed in the Declaration of Helsinki.

CT images of the patients had been acquired using a Siemens SOMATOM 128 Definition CT Scanner (120 kVp tube voltage, 512 × 512 acquisition matrix, 1.0 mm slice thickness, 0.9–1.0 pitch, 250 mAs baseline tube current with automated dose modulation using CareDose^{TM}, 300–400 mm field of view, estimated dose equivalent (EDE) 0.969 rem) [21]. Each cadaveric control femur had been aligned in neutral [22] and imaged with a GE High Speed CTI Single Slice Helical CT Scanner (100 kVp tube voltage, 512 × 512 acquisition matrix, 1.0 mm slice thickness, 1.0 pitch, 100 mAs tube current, 160 mm field of view).

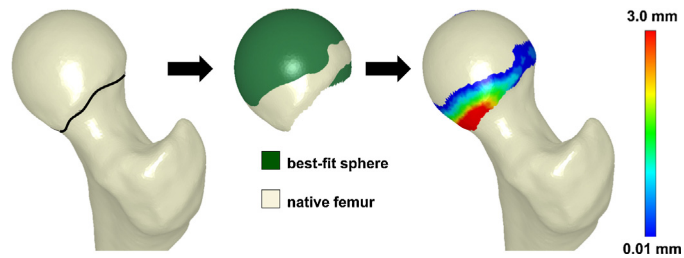

Fig. 1. Process of femoral head isolation and sphere fitting. Left: The femoral head was delineated from the neck using inflection points around the circumference of the head-neck junction (black line). Middle: The isolated head (off-white) was then projected onto the best fitting sphere surface (green). Right: Deviations (mm) between the femur and the best-fit sphere were calculated across the isolated surface of the head.

2.2. 3D Reconstruction and sphere fitting

In our previous study [21], femurs were semi-automatically segmented from the CT image data using Amira (v5.4, Visage Imaging, San Diego, CA) and 3D reconstructions were generated for each subject [23]. To improve resolution of the segmentation mask, and decrease segmentation artifact, CT images had been up-sampled to 1536 × 1536, 0.3 mm thickness for patients and 1024 × 1024, 0.5 mm for controls.

Femoral asphericity was reported in the previous study, according to the following sphere-fitting technique [21]. First, a contour map of principal curvatures was created for the entire femur. Next, a cutting surface was fit to points of inflection (curvature = 0) to define the head-neck boundary. The femoral head was identified as the section of the femur proximal to the cutting surface (Fig. 1). PreView (http://mrl.sci.utah.edu/software/preview) was used to determine the radius and center of the sphere which best fit the isolated head, via linear least-squares-minimization. Next, a spherical surface was generated by projecting nodes from the native femoral head onto the best-fit sphere (Fig. 1). Finally, asphericity was calculated as the maximum deviation (i.e. distance) between nodes on the native head and the best-fit sphere surface (Fig. 1).

2.3. Generation and alignment of digitally reconstructed radiographs

Digitally reconstructed radiographs (DRR) were used in the present study to simulate five common radiographic views used to diagnosis cam FAI. DRRs are generated from CT data using ray casting to produce an image similar to a clinical radiograph [24]. DRRs were utilized because they could be generated from controlled perspectives with respect to the CT image stack. In doing so, bias in alpha angle measurements caused by inconsistencies in inter-subject positioning was eliminated as was unnecessary radiation exposure that would be required to acquire all five radiographic projections in a standard fashion. Before completing the principal study, which was to correlate alpha angles to 3D measures of asphericity, a separate validation study was completed to demonstrate that alpha angles measured on DRRs were nearly identical to those from traditional radiographs (see Appendix).

For the principal study, DRRs were generated in Amira to simulate the: standing anterior-posterior (AP), standing frog-leg lateral, Dunn view with 45° flexion and neutral rotation, Dunn view with 45° flexion and 40° external rotation, and the cross-table lateral view. First, a DRR was generated from the complete CT image dataset (Fig. 2a and b). Then, the segmentation mask used to generate the 3D femur model was combined with the DRR to isolate image data of the femur only (Fig. 2c and d).

DRR images simulating each of the five projection views were created as follows (example for the standing frog-leg lateral in