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BASIC RESEARCH

What Is Normal Femoral Head/Neck Anatomy? An Analysis of Radial CT Reconstructions in Adolescents

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Abstract

Background Cam morphology in femoroacetabular impingement has been implicated in the development of osteoarthritis. The alpha angle and femoral head/neck offset are widely used to determine femoral head asphericity. To our knowledge, no study has evaluated the alpha angle circumferentially using three-dimensional imaging in a population of healthy individuals of adolescent age.

Questions/purposes We sought to (1) determine normal values for the alpha angle in adolescents, (2) define the location along the neck with the highest alpha angle, and (3) determine normal femoral head and neck radii and femoral head/neck offset.

Methods Fifty CT scans from a database of scans obtained for reasons not related to hip pain were studied. The average age of the subjects was 15 years (range, 14–16 years). Alpha angle and femoral head/neck offset were measured circumferentially.

Results The alpha angle averaged 40.66 ± 4.46 mm for males and 37.77 ± 5.65 mm for females. The alpha angle generally was highest between the 11:40 and 12:40 o'clock and between the 6:00 and 7:40 o'clock positions. The femoral head radius was 24.53 ± 1.74 mm for males and 21.94 ± 1.13 mm for females, and the femoral neck radius was 16.14 ± 2.32 mm for males and 13.82 ± 2.38 mm for females. The mean femoral head/neck offset was 8.39 ± 1.97 mm for males and 8.13 ± 2.27 mm for females.

Conclusions In this healthy population of 14- to 16-year-old subjects, the highest alpha angle was at the superior and inferior aspects of the heads rather than at the anterosuperior aspect. This information will provide benchmark values for distinction between normal and abnormal morphologic features of the femoral head.

Level of Evidence Level III, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Femoroacetabular impingement (FAI) is a pathomechanical process that has been linked to the development of osteoarthritis of the hip [2, 3]. It has been defined as abnormal contact between the femoral head and neck and the rim of the hip socket during normal activities such as sitting. FAI has been classified into two broad categories—the cam and pincer types. Cam impingement typically is seen in young males with an abnormal-shaped femoral head, whereas pincer type generally is the result of acetabular rim issues such as an excessively deep socket as seen in coxa profunda or localized overhang in the setting of acetabular retroversion.

Cam-type FAI has been noted in younger patients [2] and has been associated with a higher risk of osteoarthritis. In cam-type FAI, the femoral head has an increased radius in certain dimensions leading to an aspherical shape [6]. The area of greatest prominence is most often in the anterolateral aspect of the femoral head and therefore is not well observed using simple AP or lateral images [9]. Radial sequence imaging using CT or MRI has been developed as a method to obtain anatomic information regarding morphologic features of the femoral head and the acetabular rim in a 360° arc [1, 8].

The asphericity of the head in cam-type FAI has been quantified using numerous methods, the most common being the alpha angle [10]. Some studies have been dedicated to characterizing abnormal morphologic features using the alpha angle [1, 4, 5, 10, 11, 13]. Rakhra et al. [11] evaluated abnormal hips using radial sequence imaging but limited it to the anterosuperior aspect (1–3 o'clock only) based on the premise that this is where more impingement occurs. They found that in pathologic FAI, the maximum alpha angle is at the anterosuperior quadrant at the 1 or 2 o'clock position. Despite these efforts, our current understanding of morphologic features of the head and neck is still lacking. Up to now, most research in this area has been performed in cohorts of patients who have FAI or, alternatively, in presumably healthy volunteers of various ages [1, 4, 5, 10, 11, 13]. Much of the literature has experienced selection bias of the symptomatic and control groups, limited numbers of images analyzed, limited locations analyzed on any given femoral head, and variations in subject age. The paucity of information in the literature compelled us to perform the current study limited to adolescent patients who presented for CT at our institution. We expected that in a population of asymptomatic adolescent patients, the maximum alpha angles would be consistent with those published in the literature and that the same regions (1 and 2 o'clock) would have the highest alpha angles and lowest femoral neck offsets as seen in the cases described by Rakhra et al. [11].

Using three-dimensional imaging, we sought to (1) determine normal values for the alpha angle in adolescent boys and girls, (2) define at what point on the circumference of the femoral neck the alpha angle is generally highest, and (3) determine normal femoral head and neck radii and femoral head/neck offset values.

Materials and Methods

Patients included in the study had a mean chronologic age of 15.6 years old (range, 14.3–15.9 years). We selected this age group based on our clinical observations that relatively few sports and activity-related changes would likely have taken place in this age group. Additionally, at this chronologic age, subjects have reached or have nearly reached skeletal maturity. All had undergone CT for issues not related to hip pain. We established CT-based radial reconstructions of the proximal femora using a standardized technique and then analyzed the images using a specific image analysis module based on point registration by an observer (LT) with secondary automatic calculation of numerous parameters involving each image. Fifty CT scans were obtained from our institutional radiographic database. All scans were obtained from patients treated for issues not related to hip pain. We selected 50 subjects based on a previous pilot study in a series of 20 trauma patients of all ages in which the morphologic data had limited variability. The indications for CT scanning were abdominal pain in 20 patients; high-energy trauma including motor vehicle accidents, bicycle accidents, and motorcycle accidents in 20 patients; assault in five patients; and other diagnoses not related to the hip in five patients. All scans were reviewed by faculty radiologists and the senior author (AAJ) confirming the absence of proximal femoral deformity or trauma. The raw imaging data in the format of Digital Imaging and Communication in Medicine (DICOM) images were entered into an imaging reconstruction program (TeraRecon™; TeraRecon Inc, Foster City, CA, USA). Radial reconstructions then were prepared (Fig. 1) using this software with a total of 18 images for each head. These reflected 36 positions around the head. Each image then was entered into a custom imaging analysis algorithm written in MATLAB® (MathWorks, Natick, MA, USA). Multiple measurements were performed by selecting various landmark points in the MATLAB® software. From these points, multiple parameters for that image were generated and were automatically output into a spreadsheet document (Excel, Microsoft, Redmond, WA, USA). These parameters included head diameter, neck diameter, head-neck offset, and alpha angle (Fig. 2). This information was analyzed using a clock system widely used clinically in the field of hip arthroscopy (Fig. 3).

Differences in each measurement were compared based on sex using the unpaired t-test. Interobserver and intraobserver reliability analysis was performed using intraclass

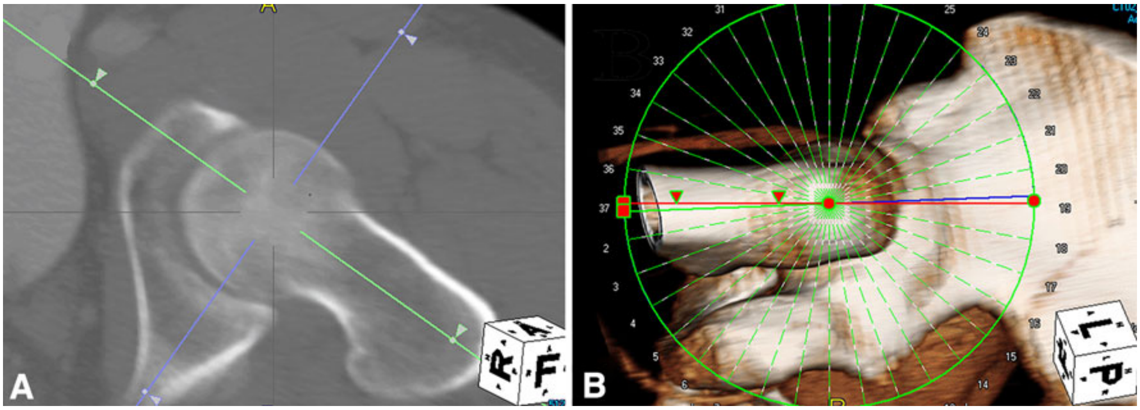

Fig. 1A–B The method for acquisition of radial reconstructions is shown using TeraRecon™ software (TeraRecon Inc, Foster City, CA, USA). (**A**) The axis of rotation is placed down the femoral neck in the axial and coronal (not shown) views. (**B**) A three-dimensional view of radial acquisitions is shown.

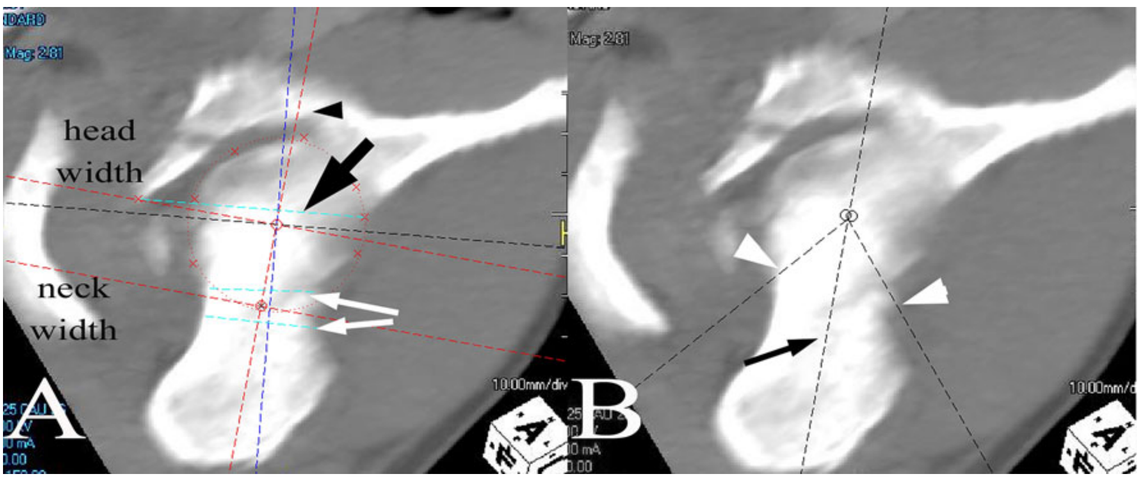

Fig. 2A–B Sample MATLAB® screen images are shown. (**A**) Points and lines of the hip are shown with red x's, which define the femoral head circumference. The white arrows show the superior and inferior extents of the femoral neck with the center point calculated as the femoral neck center. The large black arrow defines the acetabular rim line extending from one edge of the rim to the next. The black arrowhead shows the head/neck axis, extending from the femoral neck center to the femoral head center. (**B**) The head/neck axis (black arrow) is shown with the calculation of the alpha angles (white arrowheads).

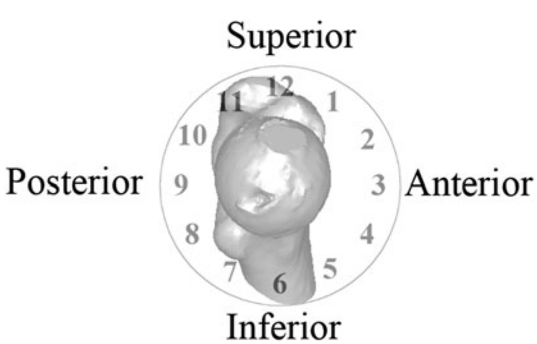

Fig. 3 This diagram shows the clock positions used in this study.

correlation coefficients (ICCs) for two observers (LT and AAJ) at two times a minimum of 4 weeks apart for five specimens (total of 360 analyses). Linear regression was performed using Excel (Microsoft). ICC and ANOVA were performed with SPSS (Version 9; IBM, Chicago, IL, USA) and StatView software (SAS Inc, Cary, NC, USA), respectively. Statistical significance was set at a probability less than 0.05.

Results

The alpha angle for all subjects and at all locations was 39.25° ± 5.28° (Fig. 4). Based on sex (Fig. 5), the alpha angle measured 40.66° ± 4.46° for males and 37.77° ± 5.65° for females ($p < 0.001$).The alpha angle generally was highest between the 11:40 and 12:20 o'clock positions and between 6:00 and 7:40 o'clock positions. In both of these regions, it measured approximately 42°.

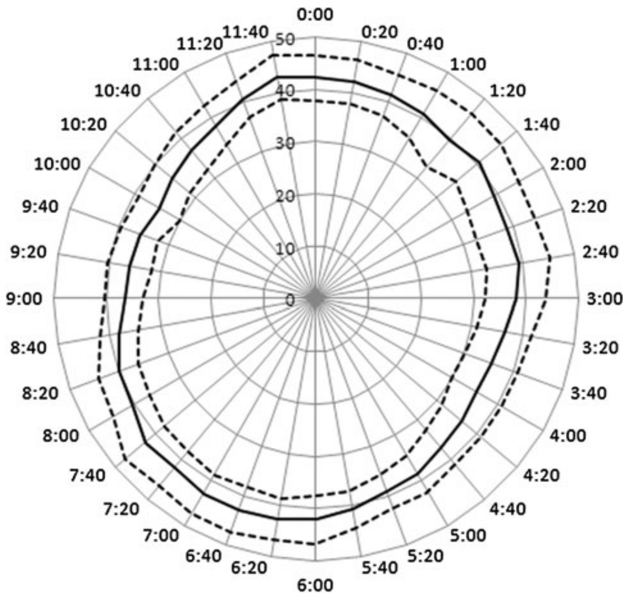

Fig. 4 Alpha angles are shown as defined by the clock position. The solid lines are averages and dashed lines are ± SD.

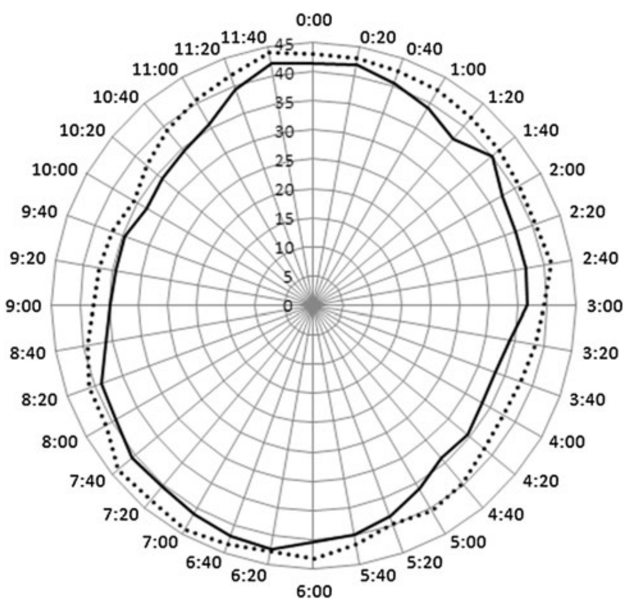

Fig. 5 Alpha angles for male and female patients are shown as defined by clock position. The solid lines are for females and dotted line for males.

The mean femoral head radius was 24.53 ± 1.74 mm for males and 21.94 ± 1.13 mm for females. The mean femoral neck radius was 16.14 ± 2.32 mm for males and 13.82 ± 2.38 mm for females (Fig. 6). Mean femoral head/neck offset was 8.39 ± 1.97 mm for males and 8.13 ± 2.27 mm for females. The mean femoral head/neck offset was lowest at the superior and inferior aspects of the head at the 12:40 and 7 o'clock positions.

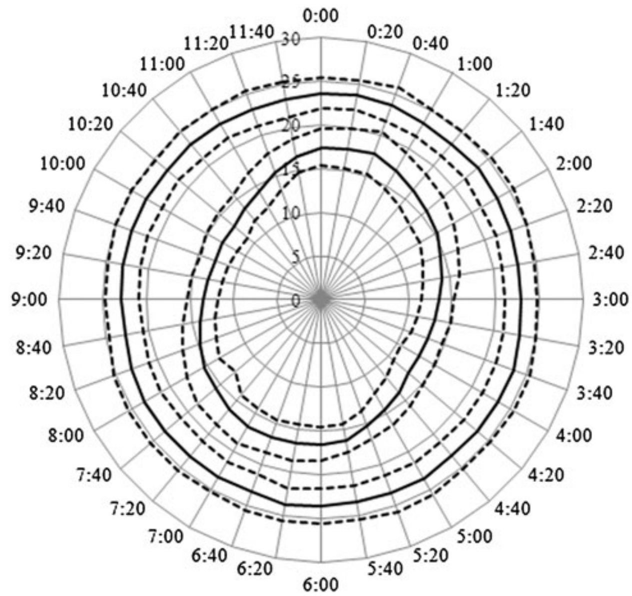

Fig. 6 Femoral head and neck dimensions are based on clock orientation as shown in Figure 3. The outer circle represents the femoral head dimension and the inner circle represents the femoral neck dimension. The solid lines are averages and dashed lines are ± SD.

In all cases, sex differences were statistically significant. As expected, the femoral head was almost perfectly spherical, whereas the femoral neck was elliptical with a slight tendency toward tilting of the superior aspect anteriorly toward the 1:00 and 7 o'clock positions.

Interobserver and intraobserver reliabilities of the analyses of the images generally were good; ICCs for the two sessions and the two observers were consistently in the range of 0.8 (Table 1).

Discussion

The distinction between normal and abnormal has been one of the central tenets of anatomic and radiologic research. In the case of morphologic features of the hip, normal can be defined in pure statistical terms as an arbitrary value above and below the mean or in pathologic terms as likely to cause injury to the joint. Our goal in this study was to define normal parameters based on a sample of subjects whose imaging was obtained for reasons other than hip disorders and also who were sufficiently young so as to render them unlikely to have sustained events leading to altered hip anatomy. Furthermore, we developed a semi-automated method to perform these measurements in such a way that any given image could be analyzed in less than 30 seconds facilitating the analysis of 900 images obtained under the identical protocol.

Table 1. Interobserver and intraobserver reliability measurements

Measurement	Interobserver ICC		Intraobserver ICC	
	Observer 1	Observer 2	Session 1	Session 2
Femoral head diameter	0.9572	0.9394	0.9482	0.9191
Femoral neck diameter	0.9761	0.9792	0.9581	0.9525
Anterior femoral head offset (offset from 6–12 o'clock positions)	0.9172	0.796	0.8268	0.7839
Posterior femoral head offset (offset from 12–6 o'clock positions)	0.8779	0.8831	0.8294	0.8251
Anterior alpha angle (alpha angle from 6–12 o'clock positions)	0.8409	0.8457	0.7888	0.7724
Posterior alpha angle (alpha angle from 12–6 o'clock positions)	0.8989	0.9114	0.8937	0.8539

ICC = intraclass correlation coefficient.

This study had numerous limitations. First, we had to surmise that the individuals studied are, in fact, representative of the normal population. We believe that the values we obtained are good normative data for the demographic population from which they were drawn. Clinical histories as obtained by review of the radiology indications and reports did not indicate any direct trauma to the hip, and we excluded images with visible hip disorders. Additionally, at our institution, CT scanning is not used in the evaluation of patients with clinical FAI or labral disorders. However, it may be possible that the population studied is not truly representative of the normal population. For example, the patients who sustained high-energy trauma may have been engaged in activities that would lead to activity-related changes in the morphologic features of their hips even at their young age. This study was limited by the availability of only the radiographic reports rather than full access to the patients' charts. Thus, data regarding height and weight of the patients were not available. These two factors could have affected the morphologic findings in this study. Despite the large amount of data obtained in the study, the total number of patients was relatively small. A larger study may have been better able to pick up outliers in the population with asymptomatic morphologic changes. Our study protocol, which was based on preexisting CT data, potentially could have missed this information. Additional sources of error could include minor changes in the axis of the femoral neck established by the radiology reconstruction program, variability based on the specific scanner used, and the patients' position in the scanner.

In this study, the mean alpha angle in a series of 14- and 15-year-old subjects was determined circumferentially around the femoral head using radial reconstruction CT scans. The results indicate that even at the position of highest asphericity, the alpha angle averages approximately 42°. The values in this study for the alpha angle are slightly lower than those in the recent literature for normal hips and markedly lower than alpha angles seen in hips with cam-type FAI (Table 2). The prevalence of cam deformities was studied in a population-based study of radiographs obtained from the Copenhagen Osteoarthritis Study [4]. There were 4151 AP pelvis radiographs from this cohort. From this group, 949 hips were excluded for various reasons including previous surgery, rheumatoid arthritis, and previous childhood hip disease. From the remaining group, the alpha angle was measured at an average of 52.6° for males and 44.9° for females. The study's major limitations included an average participant age of 60 years and the limited value of the alpha angle obtained from standard AP pelvis radiographs. Such measurements are prone to various projectional artifacts based on the exact orientation of the femur. Notzli et al. compared MR images of 39 symptomatic hips with 35 normal asymptomatic hips. According to their study, the mean alpha angle was 42° ± 2.2° in the control group and 74.0° ± 5.4° in the symptomatic group [10]. The images used in that study correspond to the 3 o'clock position used in our study and are comparable in value. Radial reconstructions obtained from CT scans have been used as a method of study by Beaule et al. [1] who performed a study of 36 painful hips and 20 asymptomatic hips with scans taken for various nonorthopaedic issues. The mean age of the control group was 37 years (range, 18–70 years). They defined the anterior alpha angle and a beta angle equivalent to the alpha angle on the opposite side of the head. The alpha angle (anterosuperior) in the symptomatic group was 66.4° ± 17.2°. The alpha angle (anterosuperior) and the beta angle (posteroinferior alpha angle) for the control group were 43.8° ± 3.85 ° and 43.8° ± 4.45°, respectively. These values closely match the values from our study despite the limited number of measurements taken, the smaller group studied, and the older average age of their group. Hack et al. [5] studied 200 asymptomatic volunteers with a mean age of 29.4 years and performed radial sequence MR images and then manually measured the alpha angle at the 1:30 o'clock position at 50.15° ± 8.13° and at the 3:00 o'clock position at 40.78° ± 7.05°.

In our study, the maximum alpha angles were found at the 12:00 superior position and the 6:00 to 7:40 position posteroinferiorly. Limited information is available in the

Table 2. Literature review

Study	Number of hips	Mean alpha angle	Type of study	Radiographic method	Reliability
Gosvig et al. [4]	3202	Alpha angles on AP pelvis radiographs: 52.6° for males and 44.9° for females; mean age approximately 60 years.	Population based cohort study	Manual measurements of standard radiographs	Reported interclass of 0.83 and ICC of 0.9 to 0.96.
Steppacher et al. [13]	50 (25 dysplastic and 25 deep acetabulum)	37.4° (range, 19°–78°) for dysplastic, 36.5° (range, 19°–89°) for deep acetabulum group	Study of clinically symptomatic patients presenting with either hip dysplasia or a deep acetabulum	Clinical MRI arthrograms with radial sequence imaging	ICC Intraobserver 1 = 0.86, ICC Intraobserver 2 = 0.79, ICC interobserver 0.81
Hack et al. [5]	400 hips	40.78° ± 7.05° at 3 o'clock position, 50.15° ± 8.13° at 1:30 position; mean age, 29 years (range, 21–51 years)	MRI arthrography evaluation in normal volunteers from a hospital and medical school	Measurements performed in a PACS system by two observers, each performing evaluation of 200 hips	Only interrater reliability presented: 0.810 ICC for axial view (3 o'clock) and 0.796 ICC for radial view (1:30 o'clock)
Beaule and Zaragoza [1]	56 hips (36 painful and 20 from asymptomatic volunteers)	66.4° ± 17.2° (anterior alpha angle) and 40.2° ± 5.4° (posterior also termed beta angle) in symptomatic hips, 43.8° ± 3.85° (anterior alpha angle) and 43.8° ± 4.45° (posterior also termed beta angle) in asymptomatic control hips.	Study of CT-based radial reconstructions	Measurements performed in a PACS system	Interclass correlation 0.60, ICC was 0.80 and 0.54 for the two observers.
Rakhra et al. [11]	41	70.5° ± 14° on maximal radial image, 53.4° ± 11.1° on oblique axial image	Analysis of 41 patients undergoing MR arthrography for FAI; evaluated the 3 o'clock position (oblique axial) and the maximal radial of the 1 o'clock or 2 o'clock position.	Manual measurements of MR arthrography images	Not performed
Notzli et al. [10]	74 (39 symptomatic, 35 controls)	74° ± 5.4° for symptomatic group, 42° ± 2.2° in the controls	MRI arthrography evaluation in symptomatic patients and normal volunteers	Manual measurements of MR arthrography images	No ICC provided
Current study	50 hips obtained from an institutional database, read as without injury, all patients 14–16 years old.	40.66 ± 4.46 mm for males and 37.77 ± 5.65 mm for females	Study of CT-based radial reconstructions	Semiautomated measurements using custom software on CT scan radial reconstructions	Interobserver ICC = 0.7724, intraobserver for Observer 1 ICC = 0.8409, intraobserver for Observer 2 ICC = 0.8457

ICC = intraclass correlation coefficient; PACS = Picture archiving and communication system; FAI = femoroacetabular impingement.

literature regarding the circumferential alpha angle in the normal population. Steppacher et al. [13] performed a comprehensive 360° evaluation of the head sphericity, epiphyseal extension, and the alpha angle using radial MRI arthrography in a series of hips with either deficient or excessive acetabular coverage, similar in principal to our study performed in normal hips. In their entire study, the alpha angle averaged 40° in the anterosuperior quadrant and 33° in the posterosuperior quadrant. Interestingly, there was no difference between the two groups in the anterosuperior region, the most likely area for clinical FAI to occur in flexion activity.

The shape of the femoral head and neck have been described qualitatively in numerous studies. Ranawat et al. [12] studied 100 hips with unilateral FAI and compared the radiographic predictors of hip pain between the symptomatic and asymptomatic sides. Overall, in their series, the male femoral head diameter was 58 mm and the female head was 52 mm [12]. Their study was performed with standard radiographs with no calibration template. Young et al. examined the symmetry between the right and left femoral heads in a series of 160 paired cadaveric femurs measured using calibrated digital photographs [14]. In their series, the mean femoral head diameter averaged 55.8 mm for males and 48.3 mm for females, and the mean femoral neck diameter was 39.3 and 33.7 mm for males and females respectively in the AP view and 23.9 and 20.1 mm for males and females respectively in the craniocaudal direction. The head and neck sizes were larger in their study compared with sizes in our study. This may be related to the average age of 32 years for their subjects and the measurement technique they used.

We have provided a comprehensive quantitative analysis of proximal femoral morphologic features in 50 subjects between 14 and 16 years old, and values that can be taken as normative of this population. The methodology used allows for efficient and consistent analysis of multiple radial reconstructions from each subject in a semiautomatic manner, thus minimizing bias. Despite the sophistication of the analysis, all measurements described in this study can be performed with essentially any radiology picture archiving and communication system or various commercially available imaging programs [7].

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