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SCIENTIFIC ARTICLE

Validity of the alpha angle measurements on plain radiographs in the evaluation of cam-type femoroacetabular impingement in patients with slipped capital femoral epiphysis

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Abstract

Objective The purpose of the study was to investigate the correlation of two different alpha angle (a-angle) measurements (“anatomical method and “three-point method”) with the anterior offset ratio (AOR), femoral head ratio (FHR), and lateral femoral head ratio (LFHR) in patients with slipped capital femoral epiphysis (SCFE).

Materials and methods We included 39 hips of 26 patients. The a-angles were measured on the frog-leg lateral view (Lat) and anteroposterior (Ap) view, FHR was measured on the Ap view, and LFHR and AOR were measured on the Lat view. A *t* test was performed to analyze the means of the alpha angles measured using the three-point method and the anatomical method, and also, a correlation was conducted to assess the association of the a-angles among the FHR, LFHR, and AOR.

Results The mean a-angles in the Ap plane in the three-point method and anatomical method were 76° ± 15° and 64° ± 10° respectively ($p < 0.001$). The mean a-angles in the Lat plane in the three-point method and anatomical method were 67° ± 13° and 56° ± 11° respectively ($p < 0.001$). The AOR showed a significant correlation only with the anatomical method a-angle values in the Lat plane ($p = 0.026$). The a-angles in the three-point method in the Lat plane did not show any significant correlation with the AOR, FHR, and LFHR. Both the FHR and LFHR values correlated significantly with the Ap plane a-angles in the three-point method and anatomical method. However, none of these correlations was strong.

Conclusions The a-angle measurement methods described in patients without femoral head–neck axis disruption may not be valid in patients with a disorder such as SCFE.

Keywords SCFE · Slipped capital femoral epiphysis · Alpha angle · Impingement

Introduction

The main deformity after slipped capital femoral epiphysis (SCFE) is incongruity of the head and neck junction of the femur, which is also named cam morphology. Alpha angle is the most commonly used measurement to diagnose cam-type impingement in symptomatic patients. Because the axis between the femoral neck and head in SCFE patients is disrupted, a general technique for measuring the alpha angle may be not useful. In the general technique (“three-point method”) described initially by Nötzli et al. [1], one line is called the femoral neck axis based on a single point at the center of the narrowest part of the femoral neck, but in order for this line to correspond to the same axis as the anatomical axis of the femoral neck, the femoral head and neck axis should not be disturbed. In other words, the femoral head should be centralized on the femoral neck. Because of the translation of the femoral head in SCFE patients, a modified alpha angle measurement that involves an anatomical axis line may be preferred instead of the ordinary alpha angle measurement technique. This technique is well described in a comparative study by Bouma et al. [2]. They used the “three-point method” and

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“anatomical method” on cadaver femora and asymptomatic subjects. The authors chose to use the anatomical centerline method to determine and report the alpha angle range in the normal population because the authors felt it more accurately represented the femoral head–neck morphology by accounting for the position of the head on the neck. According to their findings, the three-point method underestimates the amount of abnormal cam morphology (smaller alpha angle) than the anatomical method. High alpha angles with the anatomical method were lower in the three-point method and vice versa for low values. In addition, they found no difference in interobserver agreement (ICC) between two methods in cadaver measurements and in radiographic measurements of asymptomatic patients. We hypothesized that in patients with SCFE, alpha angle measurements should be different from the traditional description, because in the latter, the femoral head is centralized on the femoral neck, whereas in these patients the femoral neck axis does not cross the femoral head center. This situation has not been questioned and discussed previously in the literature in patients with SCFE. Anatomical method measurement may also account for femoral head translation, as measured by the anterior offset ratio (AOR), femoral head ratio (FHR), and lateral femoral head ratio (LFHR) [2–4] because these measurements also use an anatomical neck axis.

The purpose of the study was to compare the alpha angle values in patients with SCFE measured using the anatomical method and the three-point method, and also investigates the correlation of two different alpha angle measurements with the AOR, FHR, and LFHR in patients with SCFE.

Materials and methods

This study was conducted following the approval of our Institutional Ethical Committee (33216249–604.01.02-E.415.26). We included 39 hips of 26 patients. We included bilateral or unilateral chronic SCFE patients treated with in situ pinning. The mean follow-up was 3.4 ± 1.6 years, and we excluded patients without epiphyseal fusion. Radiographs were taken in anteroposterior (Ap), frog-leg lateral (Lat), and 45° Dunn planes. The radiographic parameters measured were the postoperative alpha angles on the Ap and Lat views, FHR on the Ap view, and LFHR and AOR on the Lat view. The Ap radiograph was performed with both legs parallel and the patellae pointing vertically, and the frog-leg Lat with the affected hip abducted to 45°, the knee flexed to 90°, and the heel resting on the medial side of the contralateral knee. The radiographs were reviewed and quantified by the authors of the study (H.U. and M.M.).

Methods of measurement of the alpha angle

The measurement of the three-point method and anatomical method was performed as in the study of Bouma et al.; in their study, the methods were very well explained [2]. For the three-point method, a best-fit circle was placed over the osseous contour of the femoral head. Next, another circle was placed over the narrowest part of the femoral neck. A line connecting the center of these two circles was drawn to determine the femoral neck axis. Then, a line was drawn between the center of the femoral head and the point at the head–neck junction where the bony contour of the femoral head first exited the best-fit femoral head circle. The alpha angle was then measured as the angle between these two lines. For the anatomical method, the axis of the neck was determined by placing three circles, touching the contour of the neck. The middle circle was the same as the three-point circle described above. The remaining two circles were placed on both sides of the first circle as far as possible, whereas the center of these circles was still on the neck. Then, a line was drawn that connects the centers of these circles to determine the femoral neck axis. The points of center of the femoral head and head–neck junction were determined as in the study of Bouma et al [2]. When necessary, the anatomical femoral neck axis was displaced so as to pass through the center of the femoral head. The angle between the femoral anatomical neck axis and the line that connects the femoral head center to the femoral head–neck junction was expressed as the alpha angle (Fig. 1a, b). For simplicity, or because of the technical necessity of the imaging software, the anatomical axis of the femoral neck can be determined by a line that connects the midpoints of two lines: the first one is drawn between the anterior and posterior outlines of the femoral neck, preferably at the narrowest area, and the second one is drawn approximately 1 cm proximally or distally parallel to the first one, which is also drawn between the anterior and posterior outlines of the femoral neck on the radiographs. The line that connects the midpoints of these two lines is identical to the anatomical axis line (Fig. 2).

Methods of measurement of the FHR and LFHR

The femoral head ratio was measured on the Ap radiographs according to Murray [5]. With this method, the midpoint of a line that is drawn between the lateral-most tip of the greater trochanter and the medial-most part of the lesser trochanter was joined to the center of the narrowest part of the femoral neck. That line extended proximally to traverse the femoral head. The greatest width on each side of this line to the outline of the femoral head was measured. The width of the medial portion divided by the width of the lateral portion is the FHR [4, 5]. The LFHR was measured in a similar way to the FHR, but in a frog-leg graph (Fig. 3). The LFHR is the posterior distance divided by the anterior distance [4].

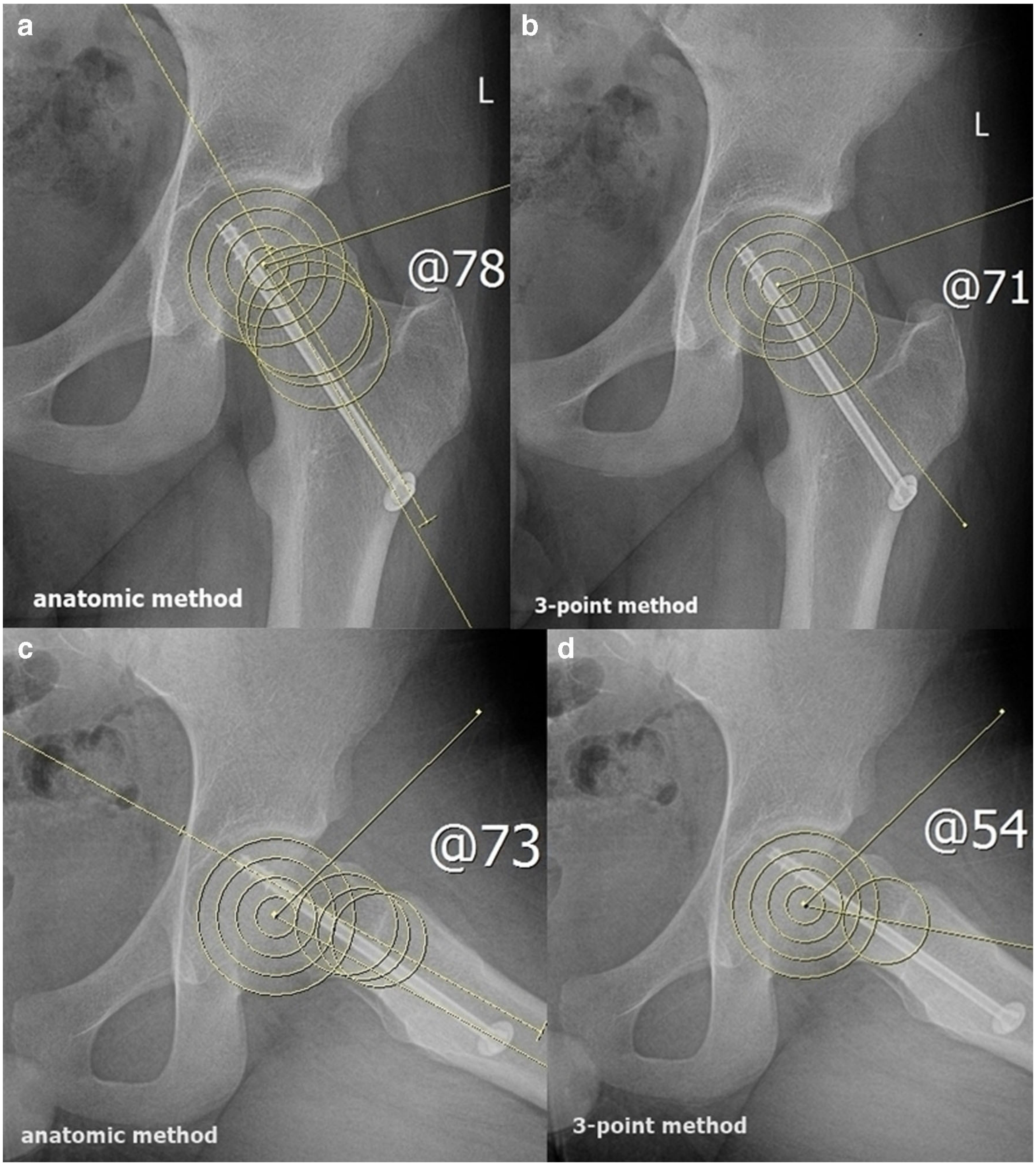

Fig. 1 **a**, **b** Anterior–posterior and **c**, **d** lateral radiographics of the hip demonstrating the alpha angle measurement according to the three-point method and the anatomical method

Methods of measurement of the AOR

The AOR was calculated by first defining the anatomical femoral neck axis. Parallel lines were then drawn along the anterior cortex of the neck and along the anterior outer part of the femoral head. The vertical distance between these two lines was the anterior offset. The diameter of the neck was determined 90° to the three lines through the center of the head (Fig. 4). The offset ratio was calculated by dividing the head–neck offset by the diameter of the head. The AOR is calculated by dividing the anterior offset by the diameter of the femoral head [3, 4, 6].

The following features suggestive of impingement that were assessed by gross visual inspection: pistol grip deformity or focal metaphyseal prominence of the femoral neck on the Ap, 45° Dunn, and frog-leg view. Positive findings were noted (Fig. 5).

All radiographs were obtained digitally using DDR Inventor V (JSB Medics Co., Bucheon City, South Korea), and measurements were taken using the Infinitt

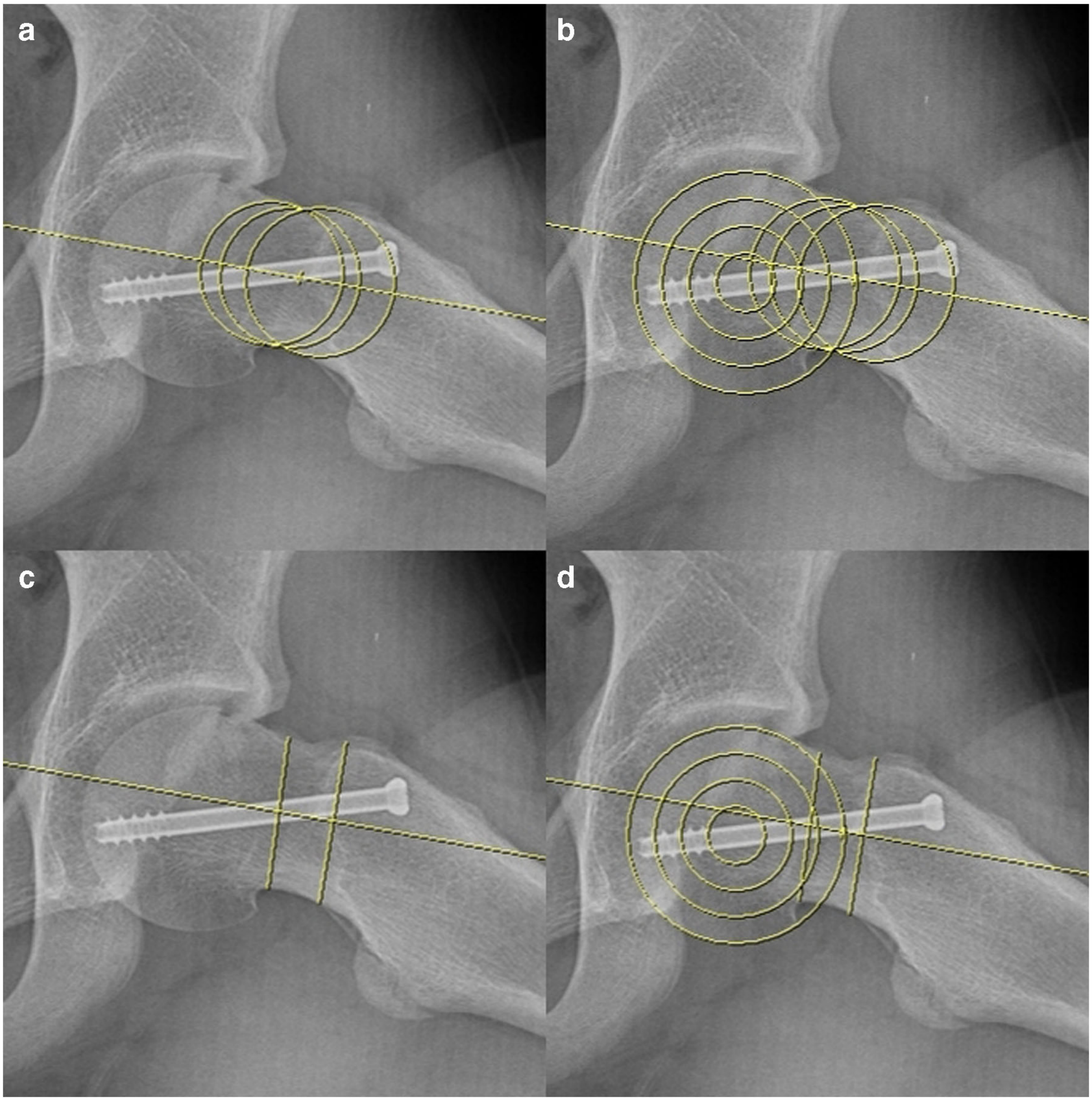

Fig. 2 **a**, **b** Anterior–posterior and **c**, **d** lateral radiographics of the hip demonstrating a simple method for determining the anatomical axis of the femoral neck

PACS System (Infinitt Healthcare Co., Seoul, South Korea) by two observers (H.U. and M.M.).

Statistics

A two-sided dependent *t* test was performed to test for differences between the two alpha angle measurement methods (three-point method and anatomical method). Pearson's correlation coefficients were determined to assess the association between the alpha angles obtained from the three-point method and anatomical method with the FHR, LFHR, and AOR. An intra-class correlation coefficient was calculated to test for an agreement between the two observers for radiographic measurements. To accurately describe the uncertainty in our results, 95% confidence intervals to the correlation coefficients and test performance measures were added. The statistical power of the study was 0.94 according to the post hoc analysis.

Results

The minimum and maximum values for the alpha angles were 47–105° in the anatomical method and 48–100° in the three-point method respectively. The mean alpha angle of the hips

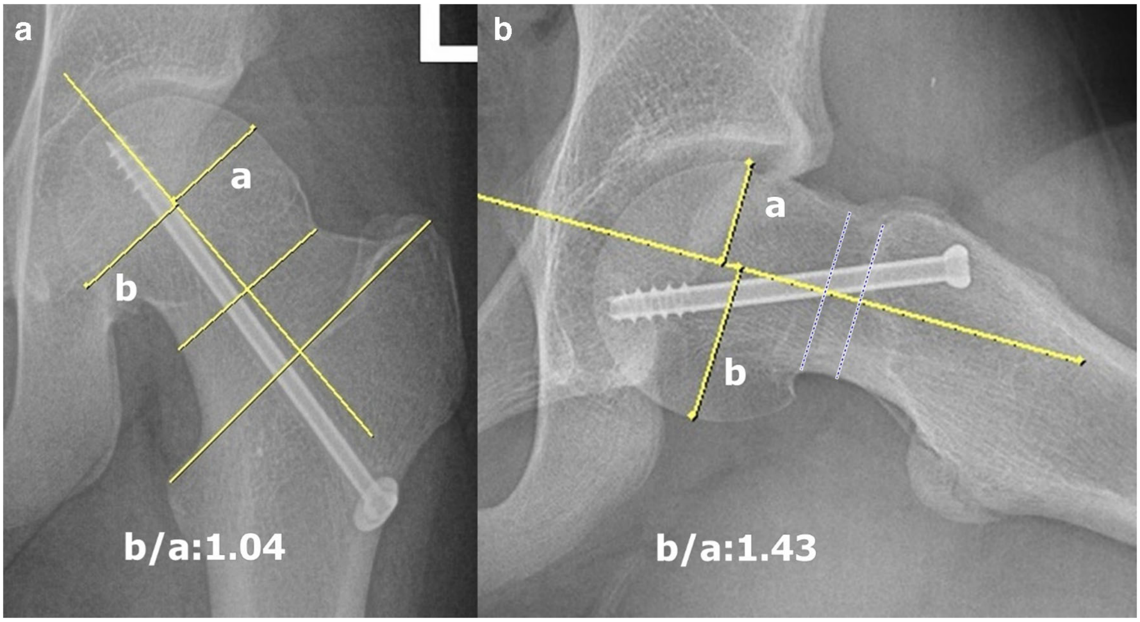

Fig. 3 **a** Anterior–posterior and **b** lateral radiographics of the hip demonstrating measurement of the femoral head ratio

according to the anatomical method is 76° ± 15° in the Ap plane and 67° ± 13° in the Lat plane. Meanwhile, it was 64° ± 10° in the Ap plane and 56° ± 11° in the Lat plane according to the three-point method. The mean difference between groups was statistically different in both planes (Table 1).

The correlations of the two alpha angle measurement methods with the AOR, FHR, and LFHR are presented in Table 2. The AOR showed a significant correlation only with the anatomical method alpha angle values in the Lat plane ($p = 0.026$). The alpha angles in the three-point method in the Lat plane did not show any significant correlation with the AOR, FHR, and LFHR.

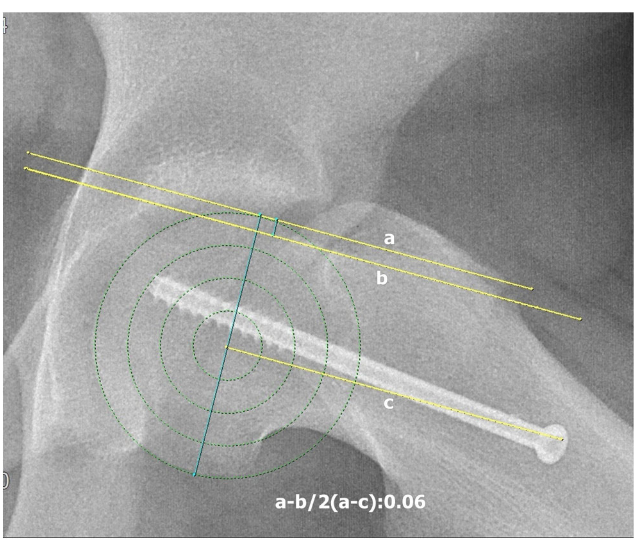

Fig. 4 Lateral radiography of the hip demonstrating the anterior offset ratio measurement

Replicate measurements of the two observers correlated significantly. The values for the correlation coefficient between the two different measurements ranged between 0.86 and 0.99.

Discussion

The most important finding of the present study was that the mean alpha angle measurement using the traditional method (three-point method) and the anatomical method yielded different values. However, in neither of these measurement methods did the alpha values correlate as expected with offset loss measurements in SCFE patients in whom the center of rotation of the femoral head has changed because the femoral head is not centralized on the femoral neck. According to our current knowledge, in patients with chronic SCFE, complex deformity occurs after in situ pinning. The determination of radiological deformity with valid techniques will enable the radiological deformity to both target and guide treatment.

In the literature, the association of radiological deformity with gait analysis and patient-reported scores was evaluated in patients with SCFE [7, 8]. In these studies, the clinical reflection of the radiological deformities was reported. However, most correlation coefficients between kinematic parameters and radiographic measures were low, indicating little correlation between the degree of radiographic deformity such as high alpha angles, which were measured using the three-point method and

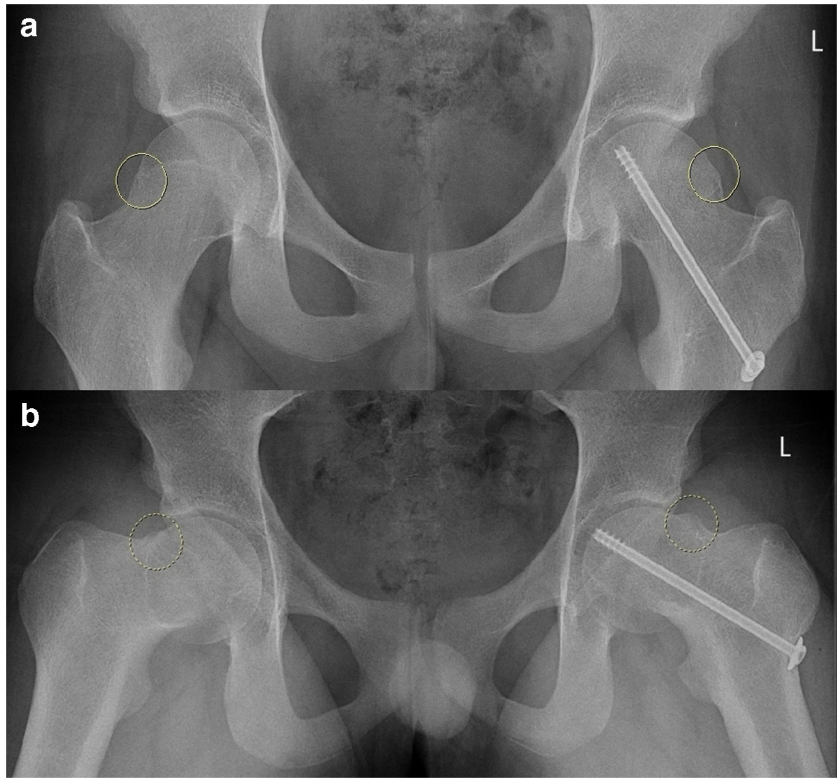

Fig. 5 **a** Pistol grip deformity in the anteroposterior (Ap) pelvis X-ray of a patient with left-sided SCFE. **b** Focal metaphyseal prominence of the femoral neck in the 45° Dunn view of the same patient. Although the pistol grip deformity or metaphyseal prominence of the nonslipped hip at the right side on the Ap view is not clear, the metaphyseal prominence on the 45° Dunn view can be detected very clearly

the severity of gait disturbance. These findings also provide a background to our study and give clues about the unreliability of the alpha angle measurement in such patients.

The deformity that occurs after femoral head epiphysis slippage is a complex deformity, and whether only the Ap or Lat plane radiological evaluations are sufficient is controversial [9]. Although the alpha angle is one of the most commonly used radiological measurements in hip impingement syndrome, the magnitude of the alpha angle may not be indicative of the size of the deformity. Because the conventional technique described by Nötzli et al. has been described in patients without a disrupted femoral head–neck axis [1], Bouma et al. showed that this measurement technique may not be appropriate in patients with impaired femoral head–neck axis [2]. They found greater correlation of AOR with the results of the anatomical method (r = 0.74) than the three-point method (r = 0.68). In our study, the correlation coefficient was 0.35 for the anatomical method, and 0.37 for the three-point method. Our correlations were smaller for both methods. However, our cohort and the study group of Bouma et al. seem to be different. Because our mean alpha angle measure was 67° with the anatomical method and 56° in the three-point method, these values were 48° and 45° respectively in the study by Bouma et al.. As the degree of deformity increases, it can be concluded that the alpha angle values measured by both methods should be questioned. Efforts to further understand the

Table 1 Mean values of radiological measurements in patients with slipped capital femoral epiphysis (SCFE)

		Mean	Standard deviation	95% confidence interval of the difference		*p* value
Alpha angle	Anatomical method Ap	76.20	15.20	71.30	81.10	<0.001
	Three-point method Ap	64.70	10.80	62.70	71.60	
	Anatomical method Lat	67.10	13.70	61.20	68.30	0.001
	Three-point method Lat	56.90	11.10	53.30	60.50	
AOR		0.07	0.05	0.05	0.08	
LFHR		1.93	0.69	1.70	2.15	
FHR		1.29	0.22	1.22	1.36	

Ap antero-posterior, *Lat* frog-leg lateral, *AOR* anterior offset ratio, *LFHR* lateral femoral head ratio, *FHR* femoral head ratio

p values represent the comparison of mean values of the alpha angle measured using the anatomical method and the three-point method

Table 2 Correlations of the two alpha angle measurement methods with AOR, LFHR, FHR

		AOR	LFHR	FHR
Anatomical method Ap	Pearson correlation	–0.085	0.321*	0.417*
	Significance (two-tailed)	0.606	0.047	0.008
Anatomical method Lat	Pearson correlation	–0.356*	0.346*	0.320*
	Significance (two-tailed)	0.026	0.031	0.047
Three-point method Ap	Pearson correlation	0.068	0.446*	0.356*
	Significance (two-tailed)	0.682	0.004	0.026
Three-point method Lat	Pearson correlation	0.037	0.267	0.244
	Significance (two-tailed)	0.823	0.100	0.134

*Significant correlation

deformity of the femoral head–neck junction in SCFE patients continue. Different radiographic views and imaging techniques have been used to assess deformities of the anterolateral femoral head–neck junction [3, 10–13]. Several Lat view radiographs, including the cross-table view, frog-leg Lat view, 90° Dunn view, and 45° Dunn view for assessing femoroacetabular impingement (FAI) have been described with varying results [14–16]. Overall, the correlations of the 45° Dunn views with the radial magnetic resonance imaging, which was accepted as a gold standard, have been reported to be stronger than the frog–leg view or cross-table views according to the diagnoses of hip impingement [11, 16].

In our retrospective study, we used the radiographs of patients who were followed up with the diagnosis of SCFE. Pelvis Ap, frog-leg Lat, and 45° Dunn radiographs were taken routinely in the follow-up of these patients in our clinic. The pelvis Ap and frog-leg radiographs were used to detect for any continued epiphyseal slippage and to evaluate the physeal closure. We use the Dunn radiograph to detect the presence of metaphyseal prominence. In our study, we measured the alpha angle on the Ap and frog-leg radiographs. As the AOR and LFHR measurements were measured on the frog-leg Lat hip radiographs, we preferred to measure the alpha angles on the frog-leg radiograph instead of the Dunn radiograph. Although the Dunn radiographs were more sensitive to FAI than other Lat radiographs, we preferred the frog-leg radiographs in our study because our objective was to show that the classically measured alpha values in SCFE patients may not be valid. In accordance with our hypothesis, we have shown that the alpha angle measurement technique, which is commonly used in the literature and described by Nötzli et al. [1], may not be valid in patients with impaired femoral head–neck axis. The mean alpha angle values were statistically different in both the Ap and Lat planes. The alpha values were higher in the anatomical method than in the three-point method. Considering the correlations of the alpha angle values obtained from both techniques with the AOR, FHR, and LFHR measurements, it is difficult to say which of the two methods (anatomical method or three-point method) is a more valid technique. Although the highest correlation coefficient was determined between the alpha angles measured in the AP plane and the LFHR using the three point technique, the alpha angles measured using the anatomical technique in the Lat plane showed a significant correlation with all of the AOR, FHR and LFHR. However, none of these correlations is strong. The correct measurement technique of the alpha angle in these patients and the cut-off values of these angles are still unknown. In future prospective studies, the correlation of these measurement methods with the clinical score of patients may be useful for the surgical management of these patients.

Our data must be viewed with limitations. First, although orthopedic radiology technicians performed the radiographs, variations in patient positioning were possible and could have affected the uniformity of the radiographs. This variability is minimized by performing the standardized technique at a single institution. The radiological measurements in this study were all expressed as degrees or ratios, meaning that the potential differences in magnification do not influence the ratings.

Conclusion

In summary, the alpha angle measurement method described in patients without femoral head–neck axis distortion may not be valid in patients with a disorder such as SCFE. Furthermore, in such patients, the cut-off values that make up the normal limit of the alpha value may be different from the previously defined limit values; thus, the diagnosis of cam FAI cannot be based solely on the alpha angle value, but rather on the overall clinical presentation. Additional research is required to better define what represents a normal femoral head–neck contour in patients with SCFE. In general, we recommend the anatomical method for alpha angle measurement, as it better characterizes the hip morphology by considering the position of the head on the neck. However, we believe that this method does not correlate with the loss of offset in high values of alpha angle measurements, that is, the reliability of the representation of the deformity is low.

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Compliance with ethical standards

Conflicts of interest None of the authors has any conflicts of interest and nothing to disclose.

Informed consent Informed consent was not obtained from the patients included in this study given the retrospective design of the study.

Ethical review committee statement This study has been approved by the ethical review committee and institutional review board of Baltalimani Bone and Joint Diseases Education and Research Hospital.

Location where the work was performed This study was conducted in Baltalimani Bone and Joint Diseases Education and Research Hospital (also the previous workplace of all authors) where all the patients underwent surgery.

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