



Exploration of femoral head coverage in screening developmental dysplasia of the hip in infants

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Abstract

Purpose To investigate the relationship of femoral head coverage (FHC) with Graf's classification for diagnosis of developmental dysplasia of the hip (DDH) and its role in evaluating hip stability.

Methods A total of 4222 hips were screened ultrasonographically with Graf's and Harcke's methods. The stability of hips was analyzed using the difference between FHCs at neutral and flexion positions (FHC-D).

Results (1) For the non-dislocated hips, the mean value of FHC at the neutral position was 59.4%, which was significantly greater than 55.0% of FHC at the flexion position ($p < 0.001$). (2) FHC at the neutral position corresponding to Graf I, IIa/b, IIc, D, III, and IV was $63.0 \pm 4.7\%$, $57.0 \pm 5.2\%$, $49.5 \pm 5.5\%$, $37.7 \pm 3.7\%$, $30.2 \pm 12.7\%$, and $7.4 \pm 11.9\%$, respectively, and that at the flexion position was $59.0 \pm 4.4\%$, $50.7 \pm 9.4\%$, $35.2 \pm 5.2\%$, $30.8 \pm 1.3\%$, $23.4 \pm 10.7\%$, and $4.7 \pm 9.9\%$, respectively, showing a statistically significant difference between the two positions. (3) The AUC of FHC-D in evaluating the stability of hips was 0.972. When the threshold was 8.5%, the sensitivity, specificity, and accuracy of FHC-D in detecting hip instability were 89.0%, 93.0%, and 93.9%, respectively.

Conclusions FHC can be used as a reference indicator for DDH classification. FHC at different positions corresponds to different reference values, and FHC-D can be used as a quantitative indicator for assessment of hip stability.

Keywords Developmental dysplasia of the hip · Ultrasonography · Femoral head coverage · Hip stability

Introduction

Developmental dysplasia of the hip (DDH) is the most common hip disease in infants and young children. It is the common nomenclature for a series of manifestations of hip abnormalities that exist when a baby is born or are developed after birth. DDH can be very mild hypoplasia, but can also be a dislocation of the hip that will cause severe loss of joint function in adulthood [1, 2]. Early diagnosis and timely intervention are key to improving treatment efficacy and reducing the long-term damage of the disease. Ultrasound has been widely accepted as the most commonly used and effective imaging method for early diagnosis of DDH. At present, the most commonly used methods of ultrasound examination are mainly static Graf's method and dynamic Harcke's method [3].

Graf's method [4] is the earliest ultrasound method for DDH examination and has been applied to classify DDH in detail by observing the shape of the acetabulum, examining the relative position of the femoral head and the acetabulum, and measuring the α and β angles. In Europe, especially in German-speaking countries, the method has become the standard method for DDH diagnosis in infants younger than 6 months old. However, accurately grasping the method is difficult [3, 5, 6] and requires systematic training [7]. If one is unclear about the relevant anatomical structure or standard image acquisition, it will be difficult to obtain reliable and reproducible results.

Harcke's method [8] is used to diagnose DDH by examining the position of the femoral head, assessing the stability of the hip and observing the morphology of the acetabulum. The assessment of stability is made by observing changes in the position of the femoral head relative to that of the acetabulum under exercise and compression. In this method, the stability of the hip is described as normal, lax, dislocatable, reducible, and not reducible. However, due to lack of a quantitative index, the method has greater subjectivity and

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empirical dependence. In 2013, the American Institute of Ultrasound in Medicine (AIUM) together with the American College of Radiology (ACR), Society for Pediatric Radiology (SPR), and the Society of Radiologists in Ultrasound (SRU) jointly published the “AIUM Practice Guideline for the Performance of an Ultrasound Examination for Detection and Assessment of Developmental Dysplasia of the Hip” based on Harcke’s method with consideration of Graf’s method. It has since become the standard method for DDH diagnosis in North America [9].

Femoral head coverage (FHC) was introduced in 1985 by Morin et al. [10] to evaluate the coverage of the femoral head by the acetabulum. Because FHC measurement is simple and easy and varies only slightly among different observers, it is suitable for screening DDH. However, Morin et al., based on FHC, divide the hip into only normal ($FHC > 58\%$) and abnormal ($FHC < 33\%$), and the relationship of FHC to Graf’s classification is unclear. Meanwhile, FHC is measured at different positions in different published reports. Some researchers adopted the neutral position [11–13], while others adopted the flexion position (hip flexion angle of 90°) [10, 14]. Since the femoral head is not a geometrical sphere, its positions detected at the neutral and flexion positions are different. To date, no relevant report has compared FHC measured at different positions. To this end, in this study, we explored the relationship between FHCs measured at different positions and their relationship with Graf’s classification. In addition, we proposed to use “difference of femoral head coverage (FHC-D)” to evaluate hip stability so as to shift the evaluation from subjective to objective and from qualitative to quantitative, and to reduce the dependence on examiner experience.

Materials and methods

Study subjects

From October 2016 to October 2017, a total of 4222 hips in 2111 infants with DDH were screened in our hospital. These infants were aged from 3 days to 7 months, with an average of 2.2 ± 1.2 months. Among them, 948 (44.9%) were males and 1163 (55.1%) were females.

Instruments and methods

The ultrasound screening was performed using a Siemens Acuson X300 Ultrasound system (Siemens Healthcare GmbH, Erlangen, Germany) with a linear transducer (7.3–11.4 MHz) and a hip measurement software package.

The infants were placed in the lateral position and comforted by family members. The tested limbs were fixed according to the sonographer’s instructions. Figure 1a–c

shows the scanning scenes. For Graf’s method, the test hip was placed in the natural position with flexion of 15° – 20° . The probe was placed parallel to the long axis of the body and perpendicular to the bed. The standard sections of all patients, except those with Graf III and IV who did not require standard section, were obtained by slightly moving or rotating the probe. In other words, the section simultaneously shows the flat ilium, lower limb of the os ilium and labrum, the hyperechoic line of the chondro-osseous junction of the femoral neck, and the hyperechoic area of synovial folds above the greater trochanter. Then, the image was fixed to measure the α and β angles for Graf’s classification. For measurement of FHC in the natural position, three lines were made at the coronal section. The first line was the straight ilium outer plate as the reference line (equivalent to the baseline of Graf’s method), and the other two parallel lines were made tangent to the medial and lateral edges of the femoral head, respectively. The ratio of the distance (d) of the line tangent to the medial femoral head to the baseline to the distance (D) of the lines tangent to the medial and lateral edges of the femoral head is FHC (Fig. 2a). The procedures for measurement of FHC at the flexion position were as follows: (1) keep the probe fixed and turn the hip of the subject 90° to the flexion position to make sure that the hyperechoic line of the chondro-osseous junction of the femoral neck and the hyperechoic area of the synovial fold above the greater trochanter disappear while other structures remain unchanged and (2) fix the image and measure FHC at the flexion position as described above (Fig. 2b). The procedures for evaluation of hip stability using Harcke’s method were the following: (1) maintain the hip at the flexion position and rotate the probe 90° to obtain the lateral transverse image of the hip at the flexion position, (2) put one hand of the family member on the sacrococcygeal part of the baby to support the hip and observe the femoral head movement under adduction and abduction of the hip, and (3) slightly move the probe to obtain a posterolateral transverse image of the hip at the flexion position and perform Barlow and Ortolani tests to examine the hip stability. If the relationship of the femoral head to the posterior acetabulum changed, the hip was defined as unstable [9] (Fig. 3). All examinations were performed by the same sonographer who has been trained in Graf’s and Harcke’s methods. All related images and videos were stored in PACS and checked by two other trained doctors. Only the cases in which a consensus was reached were included in the analysis.

Statistical methods

Data were processed statistically with SPSS 22.0 (SPSS, Chicago, IL, USA). Pearson correlation coefficient was used for correlation analysis. Quantitative data were presented as mean \pm standard deviation ($\bar{X} \pm S$) or median (M), and the



Fig. 1 Images showing the scanning scenes. **a** Neutral position for obtaining standard section (the infant was placed in the lateral position. The test hip was placed in the natural position with flexion of 15°–20°. The probe was placed parallel to the long axis of the body and perpendicular to the bed). **b** Scanning at the flexion position (90°

of hip flexion). **c** Barlow and Ortolani tests (the probe was rotated 90° and moved backwards slightly. One hand of a family member was put on the sacrococcygeal part of the baby to support the hip. Barlow and Ortolani tests were conducted by the examiner)

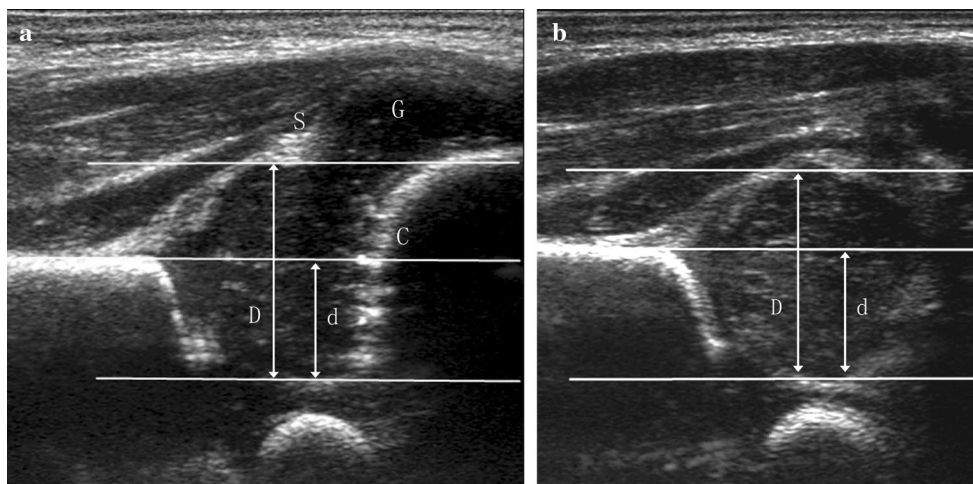


Fig. 2 Images showing FHC measurement of stable hip. **a** Image of hip at the neutral position. **b** Image of hip at the flexion position. *d* distance of the line tangent to the medial femoral head to the base-

line, *D* distance of the line tangent to the medial and lateral edges of the femoral head, *G* greater trochanter, *S* synovial fold, *C* chondro-osseous junction

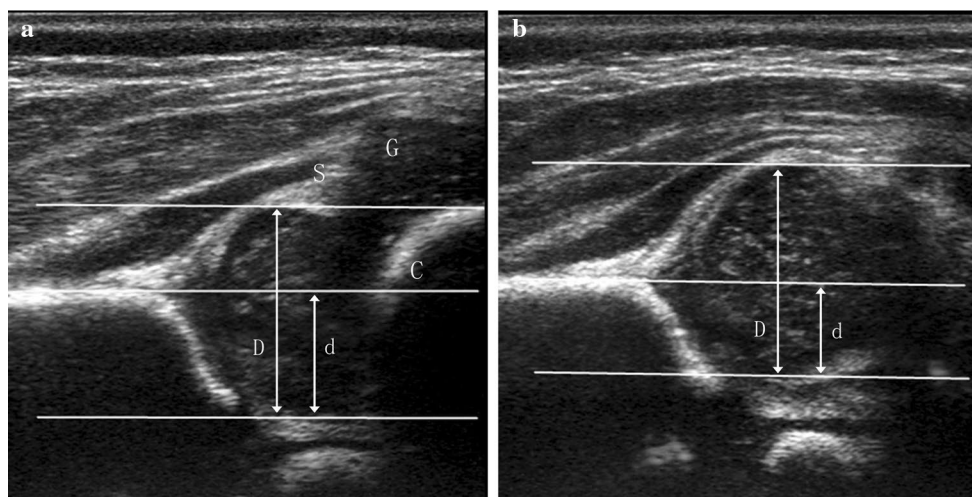


Fig. 3 Images showing FHC measurement of unstable hip. **a** Image of hip at the neutral position. **b** Image of hip at the flexion position. *d* distance of the line tangent to the medial femoral head to the base-

line, *D* distance of the line tangent to the medial and lateral edges of the femoral head, *G* greater trochanter, *S* synovial fold, *C* chondro-osseous junction

differences between groups were analyzed using paired *t* test, analysis of variance, or rank sum test. Receiver operating characteristics (ROC) curve analysis was used to determine the cutoff values and corresponding sensitivity, specificity, and diagnostic accuracy for FHC and FHC-D. The level of significance was set at $P < 0.05$.

Results

Correlation of FHC with α angle

The Pearson correlation coefficient (*r*) of FHC at the neutral position with the α angle was 0.680 ($P < 0.001$), and the Pearson correlation coefficient (*r*) of FHC at the flexion position with the α angle was 0.737 ($P < 0.001$), indicating that FHC measured at both the neutral and flexion positions had a strong positive correlation with the α angle. Because Graf III and IV hips lack the standard section, the α angle was not measured. Correspondingly, correlation analysis was not performed for these two types of hips.

Comparison of *d* and *D* values measured at neutral and flexion positions

For stable hips, the *d* value of the neutral position was the same as the *d* value of the flexion position, and their difference was not statistically significant ($P > 0.05$). By contrast, the *D* value of the neutral position was smaller than that of the flexion position, and their difference was statistically significant ($P < 0.05$). For unstable hips, the *d* value of the

Table 1 Comparison of *d* and *D* values at neutral and flexion positions

	<i>n</i>	Neutral	Flexion	<i>t</i>	<i>P</i>
<i>d</i>					
Stable	4056	10.2 ± 2.4	10.2 ± 2.6	0	> 0.05
Unstable	166	5.8 ± 5.5	4.4 ± 4.1	2.6	< 0.05
<i>D</i>					
Stable	4056	16.9 ± 2.2	17.1 ± 2.1	4.2	< 0.05
Unstable	166	15.5 ± 2.7	16.1 ± 2.3	2.2	< 0.05

neutral position was greater than that of the flexion position, while the *D* value of the neutral position was smaller than that of the flexion position, and their differences were both statistically significant ($P < 0.05$) (Table 1).

Comparison of FHC measured at neutral and flexion positions, and hip stability assessment with FHC-D

The FHC of all examined hips at the neutral and flexion positions were measured and compared using paired *t* test. The results showed that FHC at the neutral position was greater than FHC at the flexion position, showing a statistically significant difference (Table 2).

Since FHC-D did not satisfy the normal distribution, it was analyzed using the rank sum test. The results showed that FHC-D of unstable hips was significantly higher than that of stable hips (Table 2). Further analysis showed an area under ROC (AUC) of 0.972 ($P < 0.001$), indicating that FHC-D was highly accurate in assessing hip stability

Table 2 Comparison of FHC at neutral and flexion positions, FHC-D between stable and unstable hips

FHC ($\bar{X} \pm S$)		FHC-D (M)		<i>t</i> / <i>Z</i>	<i>P</i> value
Neutral (%)	Flexion (%)	Stable (%)	Unstable (%)		
59.4 ± 6.7	55.0 ± 9.3	3.0	14.0	19.12/– 13.112	<0.001

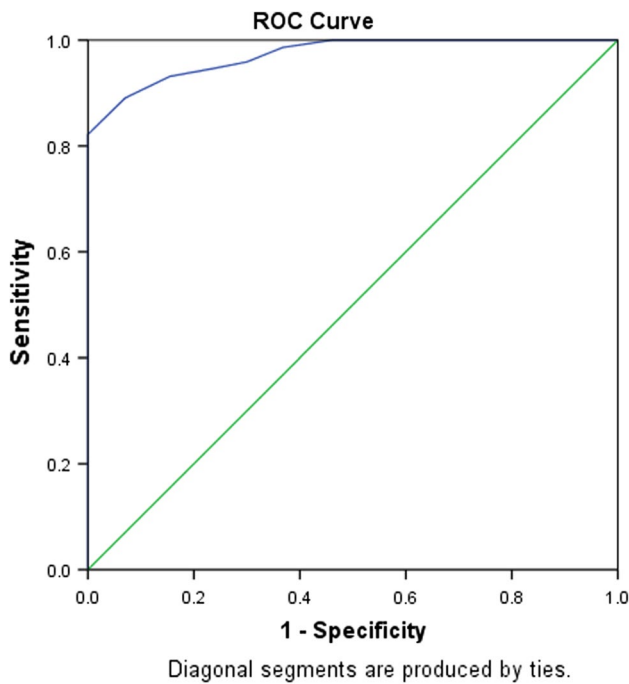


Fig. 4 ROC curve when using FHC-D to diagnose hip stability

(Fig. 4). The cutoff value was 8.5%, i.e., $FHC-D \geq 8.5\%$ indicated unstable hips with a sensitivity of 89.0%, specificity of 93.0%, and accuracy of 93.9%.

Because dislocated hips must be unstable, we only assessed the stability of non-dislocated hips.

Diagnosis of DDH using FHC at neutral and flexion positions

The ROC curve was used to analyze the effect of FHC at the neutral and flexion positions on DDH diagnosis (Fig. 5). The results showed that the AUC of FHC at the neutral position was 0.884 and that at the flexion position was 0.879, indicating that both of them have certain accuracy in DDH diagnosis.

The 95% confidence interval of AUC for FHC at the neutral position was 0.858–0.910, which overlapped with that of 0.850–0.907 for FHC at the flexion position, indicating that there was no significant difference in their DDH diagnostic ability (Table 3). In addition, using FHC for the diagnosis of DDH showed that (1) with the cutoff value of 58.5% at the neutral position, its sensitivity, specificity, and accuracy

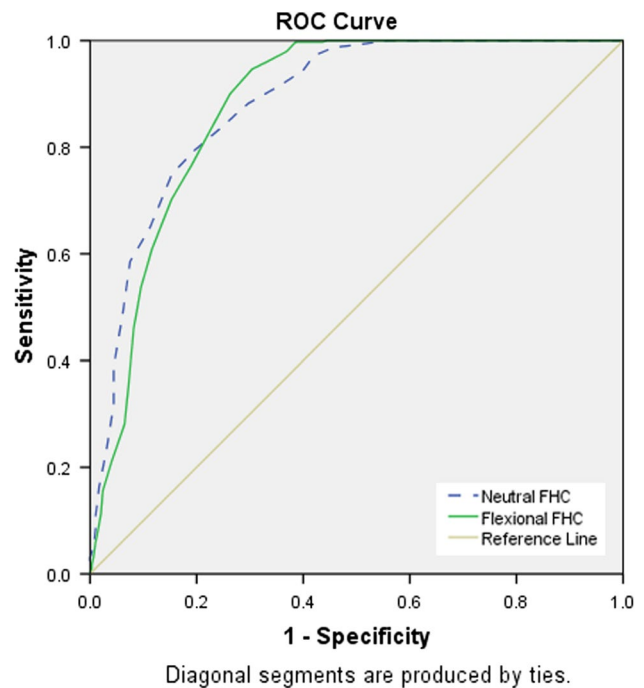


Fig. 5 ROC curves when using FHC at the neutral and flexion positions for DDH diagnosis

for DDH were 80.5%, 79.3%, and 79.8%, respectively, and (2) with the cutoff value of 52.5% at the flexion position, its sensitivity, specificity, and accuracy for DDH were 69.6%, 94.6%, and 83.9%, respectively (Table 3). Taken together, the diagnosis of FHC at the flexion position was slightly better than that at the neutral position, but the difference was not statistically significant.

Correspondence of FHC at different positions with Graf’s classification

With the increase in severity of DDH using Graf’s method, the value of FHC gradually decreased. In different Graf types, the value of FHC at the neutral position was not the same as the value of FHC at the flexion position, showing a statistically significant difference ($P < 0.001$). FHC differences were statistically significant for any type of hips ($P < 0.05$) (Table 4). Because the range of the α and β angles of type IIa and type IIb hips was the same, they were combined into one class for analysis.

Table 3 Comparison of DDH diagnosis using FHC at neutral and flexion positions

Position	AUC	P value	Cutoff value (%)	95% CI of AUC	Sensitivity (%)	95% CI	Specificity (%)	95% CI	Accuracy (%)	95% CI
Neutral	0.884	< 0.001	≤ 58.5	0.858–0.910	80.5	77.5–83.5	79.3	73.4–85.2	79.8	73.5–85.5
Flexion	0.879	< 0.001	≤ 52.5	0.850–0.907	69.6	66.6–72.6	94.6	91.6–97.6	83.9	80.9–86.9

Table 4 Correspondence of Graf's classification with FHC at different positions

	n (%)	FHC at neutral position		FHC at flexion position	
		$\bar{X} \pm S$	95% CI	$\bar{X} \pm S$	95% CI
I	2629 (62.27)	63.0 ± 4.7 ^a	62.9–63.2	59.0 ± 4.4 ^a	58.57–59.44
IIa/b	1415 (33.52)	57.0 ± 5.2 ^b	56.7–57.3	50.7 ± 9.4 ^b	49.26–52.05
IIc	91 (2.16)	49.5 ± 5.5 ^c	48.3–50.7	35.2 ± 5.2 ^c	33.32–37.05
D	6 (0.14)	37.7 ± 3.7 ^d	33.8–41.5	30.8 ± 1.3 ^d	29.44–32.23
III	58 (1.37)	30.2 ± 12.7 ^e	26.9–33.6	23.4 ± 10.7 ^e	20.52–26.19
IV	23 (0.54)	7.4 ± 11.9 ^f	2.3–12.5	4.7 ± 9.9 ^f	0.38–8.92
F	–	1255.011	–	543.081	–
P	–	< 0.001	–	< 0.001	–

Different letters “abcdef” indicate a significant difference ($P < 0.05$) between two groups

Discussion

Besides the classical Graf's and Harcke's methods, FHC, as an evaluation method for DDH, has the advantages of simple and easy operation and small measurement error. However, the correspondence of FHC to Graf's classification has not been reported in the relevant literature [10]. In this study, we attempted to analyze their relationships. The results showed that FHC had a strong positive correlation with the α angle and was related to Graf's classification. The differences among different types were statistically significant.

Graf concluded that FHC measurement was not comparable because the femoral head was not a regular sphere. Our study also showed that there was a statistically significant difference in FHC of the same hip measured at different positions, but FHC measured at the same position was comparable. Therefore, for the correspondence between FHC and Graf's classification, different body positions should be distinguished and corresponded to different reference ranges. ROC curve analysis showed that the diagnostic value of FHC measured at the flexion position was slightly better than that of FHC measured at the neutral position in diagnosing DDH, but the difference was not statistically significant.

In practice, it is feasible to measure FHC at both the neutral and flexion positions. But the position needs to be indicated in the report, and FHC should be measured at the same position at later follow-up examinations.

The most commonly used method to evaluate hip stability by ultrasound is Harcke's method. Based on the observation of change in the relationship between the femoral head and the acetabulum under exercise and compression, the stability of the hip is described as normal, lax, dislocatable, reducible, and not reducible. Except for normal, the other four types are unstable. In the AIUM (2013 edition) guideline, the term “unstable hip” is defined as “If the relationship of

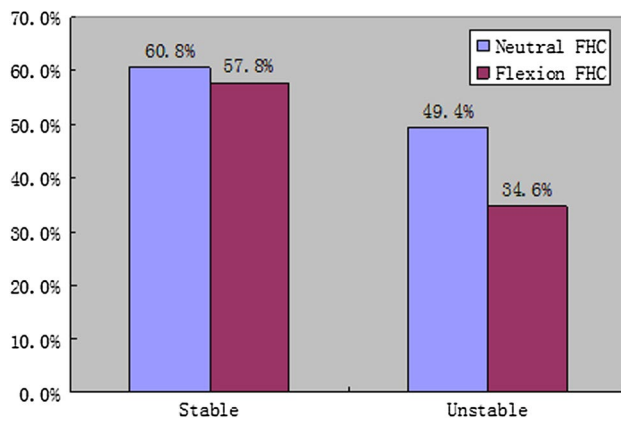


Fig. 6 Average FHC histogram of stable and unstable hips at the neutral and flexion positions

the femoral head to the posterior acetabulum changes with gentle stress, the hip is unstable” [9]. However, due to lack of a quantitative index, stability assessment with Harcke’s method is subjective and empirical. In this study, we showed that compared with that of stable hips, FHC of unstable hips at both the neutral and flexion positions was significantly lower. In particular, the reduction of FHC at the flexion position was more pronounced (Fig. 6). The FHC-D was much greater in unstable hips than in stable hips. Thus, it could be used to evaluate hip stability to make up for the deficiencies of Harcke’s method. The AUC of FHC-D for judging hip stability is 0.972, indicating it is highly accurate. When FHC-D is $\geq 8.5\%$, the diagnostic accuracy reaches 93.9%.

The study was performed by the same sonographer who was trained in Graf’s and Harcke’s methods using the same equipment to minimize system error. The included images and videos were independently examined by two other doctors to improve the reliability of the results. However, there were still some limitations. First, the number of D-type and unstable hips was small. Thus, there may have been sampling errors. Second, the reference standard in the assessment of stability was subjective in itself, so the final result still had certain inevitable subjectivity. Of course, the morphology of hips still needs to be assessed in an ultrasound examination. Biological measurement is only a part of ultrasonography. A variety of integrated approaches is conducive to obtaining a comprehensive and objective examination result.

Conclusions

Femoral head coverage can be used as one of the classification indicators of DDH. FHC at different positions corresponds to different reference values. FHC-D can be used as a quantitative index to evaluate hip joint stability.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical statements All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

Informed consent Informed consent was obtained from all patients for being included in the study.

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