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ORIGINAL ARTICLE

Use of ultrasonography to evaluate early outcomes of reduction in developmental dysplasia of the hip

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Abstract

Objective To compare pubo-femoral distance (PFD) in normal hips and those treated for developmental dysplasia of the hip (DDH) and to investigate the value of ultrasonography from the medial hip in early follow-up of dislocated DDH after reduction.

Materials and methods This study included 58 infants (49 females) with DDH who presented with 65 dislocated hips (51 unilateral and 7 bilateral). Dislocation was treated by closed reduction for 53 and open reduction for 12 hips. Ultrasonography on the medial side of the hip was performed within 1–2 weeks and 4 weeks after reduction. The distance from the pubic bone to the femoral head (PFD) was measured to assess the reduction and stability of the femoral head and compared to that on the contralateral side (control) in cases of unilateral DDH.

Results The PFD value for the normal group (2.9 ± 0.4 mm) was significantly less than that for the closed reduction group (4.9 ± 2.8 mm, $P<0.001$) and that for the open reduction group (4.4 ± 1.6 mm; $P=0.02$), but no difference in the PFD was observed between the closed reduction and the open reduction groups ($P=0.73$). Despite successful reduction, the PFD values in the successful reduction group remained higher than those of the normal hips.

Conclusion PFD measurement by ultrasonography of the medial hip can be used to evaluate the effectiveness of reduction procedures in DDH. The clinical implications of post-reduction ultrasound evaluation in the diagnosis and long-term follow-up of outcomes require further research.

Keywords Developmental dysplasia of the hip · Hip · Infants · Outcome · Treatment · Ultrasound

Introduction

Developmental dysplasia of the hip (DDH) is the most common orthopedic condition in infants, and its early diagnosis and treatment are important for assessment of residual deformity and prognosis [1–4]. If reduction of the hip joint is unsuccessful 3 weeks after open or closed reduction and immobilization, other treatment modalities need to be considered [5].

Conventionally, pelvic anteroposterior (AP) radiographic examination has been used to evaluate DDH before and after reduction. However, radiograph examination is limited by the lack of ossification of the infant femoral head, and posterior dislocations may be missed. Clinical examination can assess relocation of the hip, but the stability and degree of reduction cannot readily be determined. Ultrasound examination of the hip joint has been performed to demonstrate the reduction status of the femoral head by measuring the

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pubo-femoral distance (PFD) to evaluate the reduction and to assess the degree of soft-tissue interposition, joint stability and congruence. Ultrasound can also be used to confirm maintenance of reduction following closed or open procedures for DDH [6, 7]. PFD measurements in the coronal plane to exclude dislocation of the femoral head after removal of treatment measures have been reported in the literature [8–12]. Our approach, assessing the PFD through the medial hip space, has been shown to be valuable in the assessment of post-reduction PFD and prediction of reduction outcomes [6, 13]. Ban et al. [7] obtained the normal range of PFDs for 0– to 12-month-old children by measuring the medial hip PFD values of 240 infants of different ages. That study provided a theoretical basis for the use of ultrasonic medial hip examination to judge early outcomes of DDH reduction. Here, we present our experience using medial hip ultrasound for post-reduction evaluation of DDH.

Materials and methods

This was a retrospective study, which was approved by the institutional review board; a waiver of consent was granted for evaluation of medical records and patient data.

Participants

Fifty-eight cases of DDH with dislocation were diagnosed in the Pediatric Orthopaedic Department of our hospital from September 2017 to October 2020, including 9 males and 49 females. The average age of the infants was 10.8 ± 4.8 months (range: 5–18 months). All patients underwent closed or open reduction as primary treatment after diagnosis of dislocated DDH. Patients who had received previous treatment, those who also had a developmental deformity other than DDH (such as arthrogryposis multiplex congenita) and those who had pathological dislocation of the hip were excluded. The normal group included the contralateral non-dislocated hips of patients with unilateral hip dislocation.

Ultrasonic examination

Ultrasonography was performed by an experienced ultrasound physician (B.Y.) with 8 years of experience in hip ultrasound and a pediatric radiologist (L.Q.) with 10 years of experience in diagnostic hip imaging using a Toshiba Aplio 500 ultrasound system (Toshiba Medical Systems Corporation, Tokyo, Japan) or a GE Logiq 9 ultrasound system (GE Medical Systems, Milwaukee, WI) with a high-frequency linear transducer (L 5-12 MHz). While the hip was immobilized in plaster, ultrasound of the medial transverse section of the hip joint was performed. Scanning via the inguinal approach displays both superior pubic rami, the ipsilateral femoral head, femoral neck and soft tissues in the acetabular fossa. Ultrasound was performed to observe the short-term outcomes of reduction (at 1–2 and 4 weeks).

Ultrasonic measurement

For each hip, a vertical line was drawn inferiorly through the lateral aspect of the superior ramus of the pubic bone. When the femoral head was not in the acetabular fossa position, the PFD was defined by measuring the shortest distance between the posterior edge of the superior pubic ramus and the anterior edge of the ipsilateral femoral head (Fig. 1). When the femoral head was in the acetabular fossa, the PFD was defined by measuring the shortest distance between this

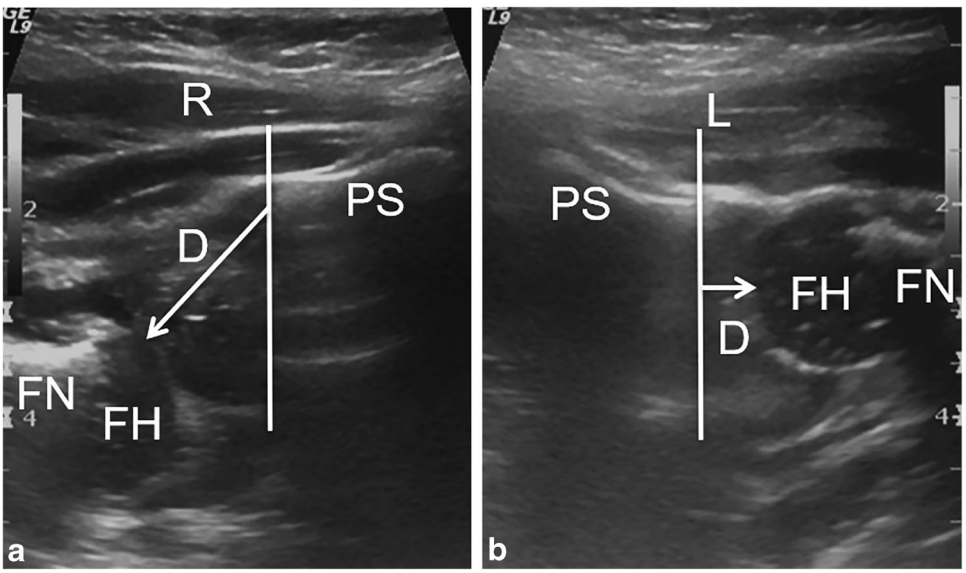

Fig. 1 Longitudinal ultrasound images (medial approach) of both proximal femurs in a 2-month-old girl with right dislocated developmental dysplasia of the hip. **a** Measuring the PFD of the dislocated right hip (*arrow*). **b** Measuring the PFD of the normally located left hip (*arrow*). *D* distance, *FH* femoral head, *FN* femoral neck, *L* left, *PFD* pubo-femoral distance, *PS* pubic superioris, *R* right

Table 1 Pubo-femoral distance (PFD) measurements on ultrasonography for each group of patients

Group	Hips (*n*)	Mean PFD ± SD (95%CI)
Normal	51	2.9 ± 0.4 mm (2.7-3.0 mm)
Closed reduction	52	4.9 ± 2.7 mm (4.2-5.8 mm)
Open reduction	13	4.4 ± 1.6 mm (3.6-5.3 mm)
Successful reduction	56	4.0 ± 1.3 mm (3.7-4.3 mm)
Unsuccessful reduction	9	9.7 ± 3.3 mm (7.6-12.1 mm)

CI confidence interval, *SD* standard deviation

tangent and the medial aspect of the femoral head (Fig. 1). Each hip was measured separately at different times on the same day by two observers, and the averages of the measurements from both observers (B.Y. and L.Q.) were recorded.

Evaluation of reduction outcomes

For all hips, concentric reduction was confirmed by intraoperative hip arthrography performed by a pediatric orthopedic surgeon (W.Y. with 36 years of experience) before and after the intraoperative plaster fixation. Successful reduction was defined as when the femoral head was in the acetabular fossa on ultrasound and the femoral head was not palpable to the clinician from the posterior buttock at 1–2 and 4 weeks after DDH reduction. Hip reduction was confirmed by pelvic AP radiograph examination. Reduction was considered unsuccessful if at 1–2 and/or 4 weeks after DDH reduction the femoral head was not in the acetabular fossa and could be palpated from the posterior buttock by the clinician. Unsuccessful hip reduction was confirmed by pelvic AP radiograph examination and/or magnetic resonance imaging (MRI). The imaging findings were reported by a radiologist (L.X.) with 35 years of experience and the clinical physical examinations were conducted by a pediatric orthopedic surgeon (W.Y.).

Statistical analysis

Statistical analyses were conducted using SPSS 13.0 (SPSS Inc., Chicago, IL). Measurements are expressed as mean ± standard deviation and corresponding 95% confidence intervals. One-way analysis of variance was used to test the associations between PFD values of the normal, closed reduction and open reduction groups as well as between the normal, successful reduction and unsuccessful reduction groups. Bland-Altman analysis was performed to evaluate interobserver reliability. $P<0.05$ indicated that a difference was statistically significant.

Results

Surgical information

This study included 65 dislocated hips, including 51 cases of unilateral and 7 cases of bilateral hip dislocation, with 39 on the left side and 26 on the right side. Fifty-three dislocated hips were treated with closed reduction and plaster external fixation, and 12 hips were treated with open reduction and plaster external fixation. The normal group consisted of the 51 contralateral non-dislocated hips of the 51 patients with unilateral hip dislocation. Three groups were formed according to condition and treatment: the normal group (n=51 hips), the closed reduction group (n=52 hips) and the open reduction group (n=13 hips).

Comparison of PFD values among groups

The PFD values for the normal group, the closed reduction group and the open reduction group were 2.9 ± 0.4 mm, 4.9 ± 2.8 mm and 4.4 ± 1.6 mm, respectively (Table 1). The differences between the normal versus closed reduction groups and the normal versus open reduction groups were statistically significant (P=0.000, P=0.02). However, the PFD values did not differ significantly between the closed reduction and open reduction groups (P=0.73).

According to reduction outcomes, the 116 hips were divided into the normal group (n=51 hips), the successful reduction group (n=56 hips) and the unsuccessful reduction group (n=9 hips). No significant differences were detected in the patients' age at the time of diagnosis or at the time

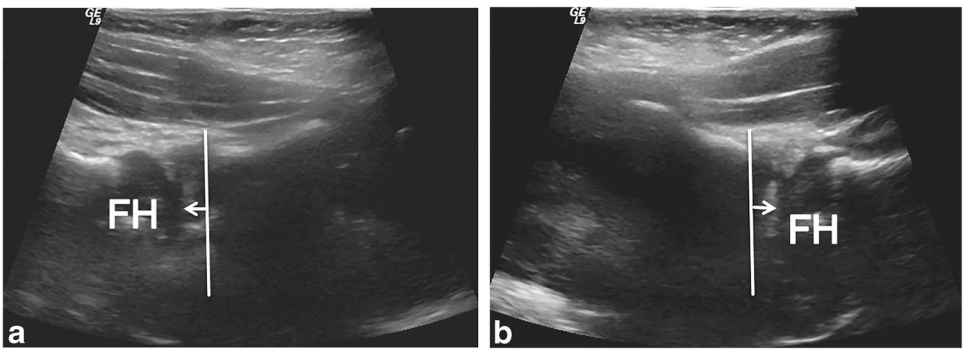

Fig. 2 Longitudinal ultrasound images (medial approach) of both proximal femurs in a 6-month-old girl with left dislocated developmental dysplasia of the hip. One week after closed reduction, both femoral heads are in the acetabular fossae. Right PFD=3.0 mm (**a**) and left PFD=3.2 mm (**b**). *FH* femoral head, *PFD* pubo-femoral distance

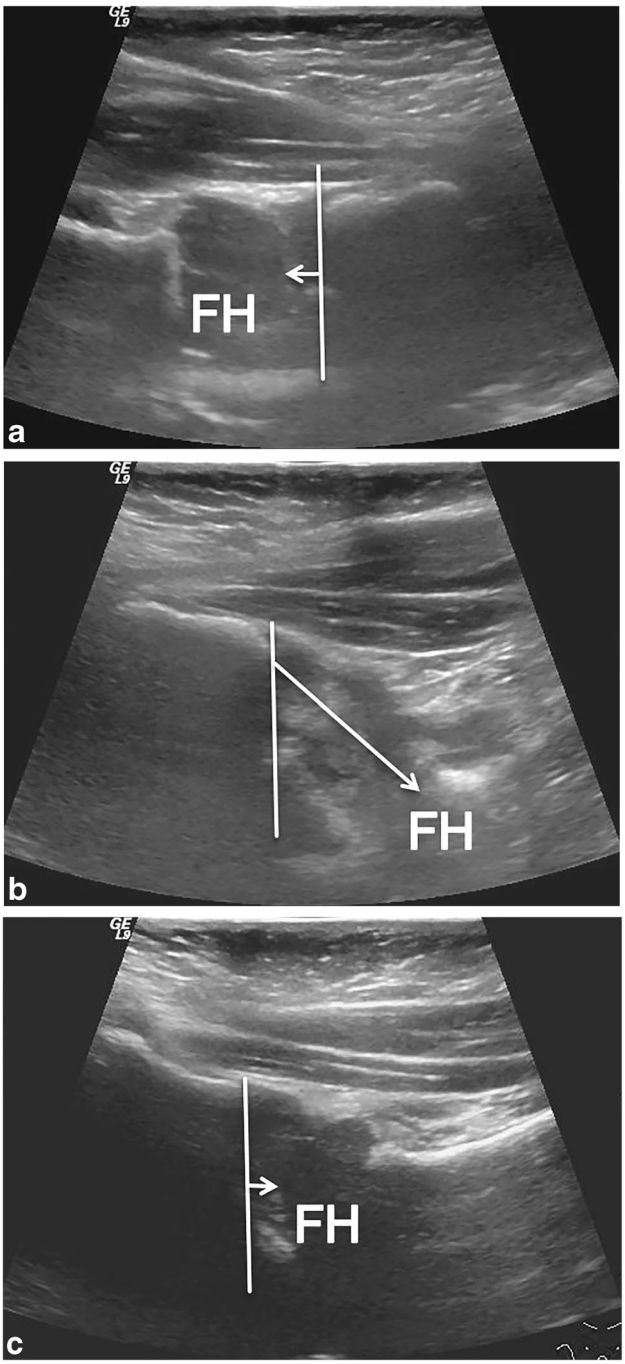

Fig. 3 Longitudinal ultrasound images (medial approach) of both proximal femurs in a 5-month-old boy with bilateral dislocated developmental dysplasia of the hip obtained one week after closed reduction (**a-c**). The right femoral head is in the acetabular fossa, and the PFD=4.0 mm (**a**). The left femoral head is not reduced and is located posterolateral to the acetabular fossa. PFD=21.1 mm (**b**). There were many abnormal hyperechoic shadows in the left acetabular fossa. After clinical manipulative reduction, a repeat ultrasound examination confirms reduction of the left femoral head, with a PFD value of 3.8 mm (**c**). *FH* femoral head, *PFD* pubo-femoral distance

of surgery between the successful and unsuccessful reduction groups (P=0.80 and P=0.80). Among the nine cases of unsuccessful reduction, six were identified during the first ultrasound examination 1–2 weeks after the reduction procedure. These hips were then manually reduced under ultrasound guidance and plaster external fixation was reapplied. Four weeks after this reduction procedure, three hips were successfully reduced, while the other three were dislocated, as identified during the second ultrasound examination 4 weeks after the reduction procedure. The PFD values for the normal group, the successful reduction group and the unsuccessful reduction group were 2.9 ± 0.4 mm, 4.0 ± 1.3 mm and 9.7 ± 3.3 mm, respectively (Table 1). Despite successful reduction, the PFD values in the successful reduction group remained higher than those of the normal hips. Typical cases of successful and unsuccessful reduction are presented in Figs. 2 and 3.

Interobserver reproducibility

The Bland-Altman plot showed good consistency in the measurements by two observers (B.Y., and L.Q., Fig. 4). Only two values were outside the consistency interval.

Discussion

DDH results from a series of morphological and structural abnormalities that occur during the in utero development of the acetabulum. Due to the limited accuracy of neonatal DDH physical examination [14–16], hip ultrasound has become a common examination method for early diagnosis [17, 18]. After DDH reduction, clinical and radiographic examination cannot directly display the relationship between the femoral head and acetabular fossa, whereas ultrasound examination has been shown to reliably reveal the position

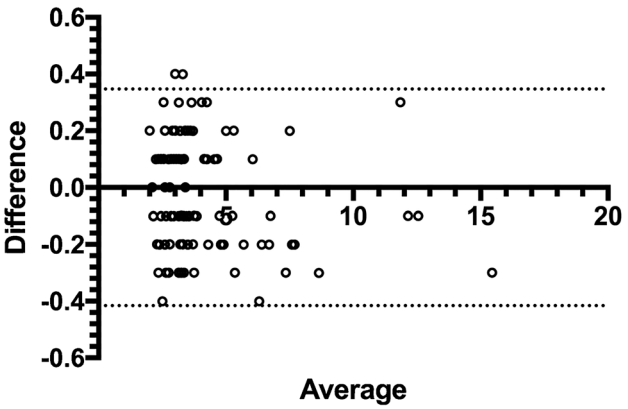

Fig. 4 Bland-Altman plot for interobserver reliability of pubo-femoral distance measurement

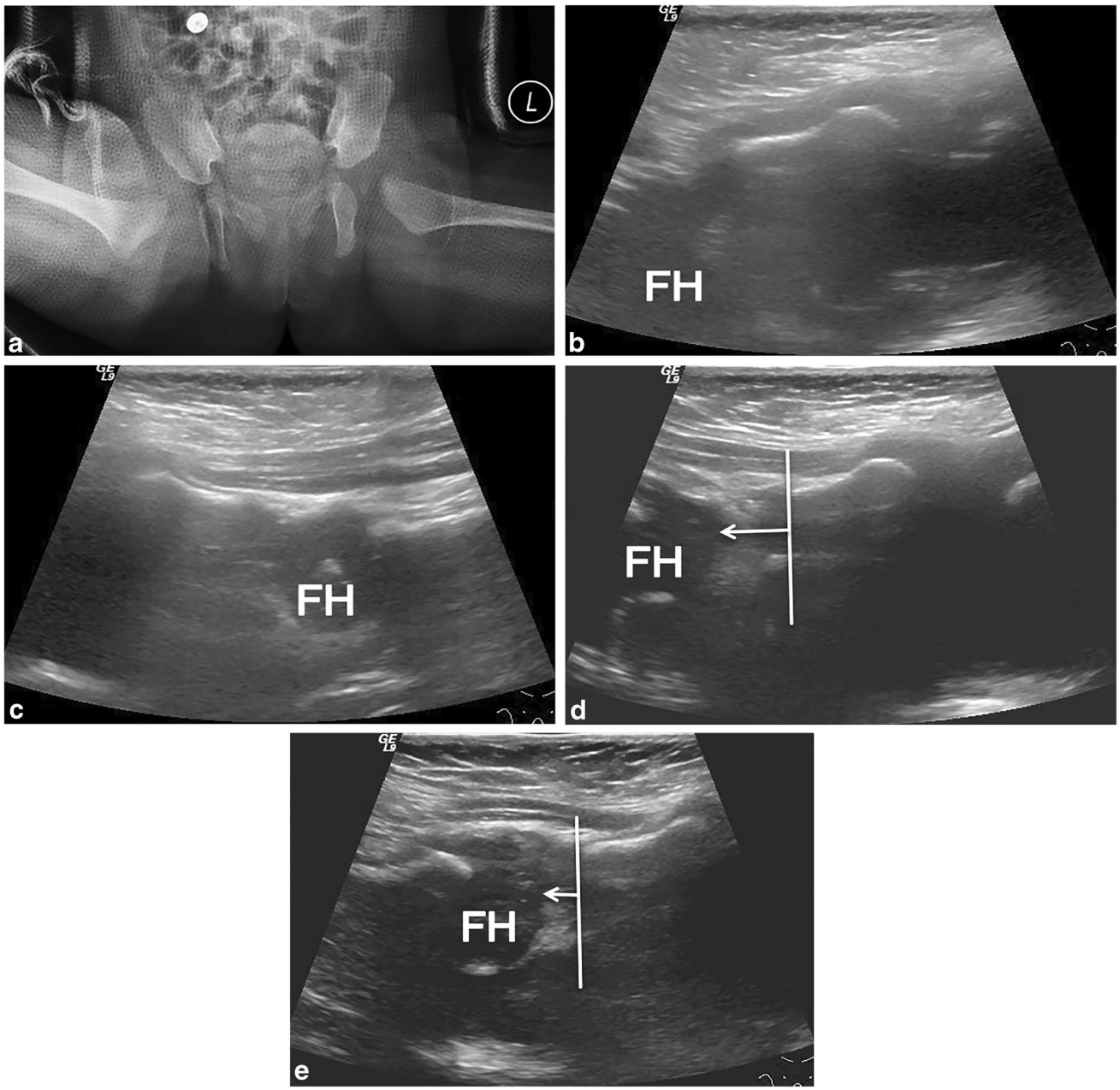

Fig. 5 Anteroposterior pelvic radiograph **(a)** and longitudinal ultrasound images (medial approach) of both proximal femurs **(b-e)** in a 6.5-month-old girl with right dislocated developmental dysplasia of the hip. One week after closed reduction, there is reduction of the right femoral head and bilateral symmetry (**a**). Two weeks after reduction, the right femoral head is not reduced and is located behind the acetabular fossa (**b**). The left femoral head is in the acetabular fossa (**c**). After clinical manipulative reduction, the right femoral head is in the acetabular fossa, with a PFD of 5.0 mm (**d**). An abnormal hyperechoic mass is seen in the acetabular fossa. Four weeks after reduction, the right PFD value has decreased to 2.8 mm (**e**). *FH* femoral head, *PFD* pubo-femoral distance

of the femoral head [13, 19, 20]. However, conventional ultrasound examination is carried out through the lateral side of the hip. In children with DDH after closed or open reduction and plaster external fixation, because of the shielding of the external fixator, the lateral side of the hip cannot be accessed for scanning. Therefore, our technique to scan the hips from the medial joint space adds value in these patients. This approach allows us to scan the hips and obtain accurate PFD measurements without removing the external fixator.

In the present study, we evaluated two methods for PFD measurement. When the femoral head is in the acetabular fossa, the sonogram shows that the superior pubic ramus, the anterior margin of the femoral head and the femoral neck are in the same horizontal plane on the medial cross section of the hip in the

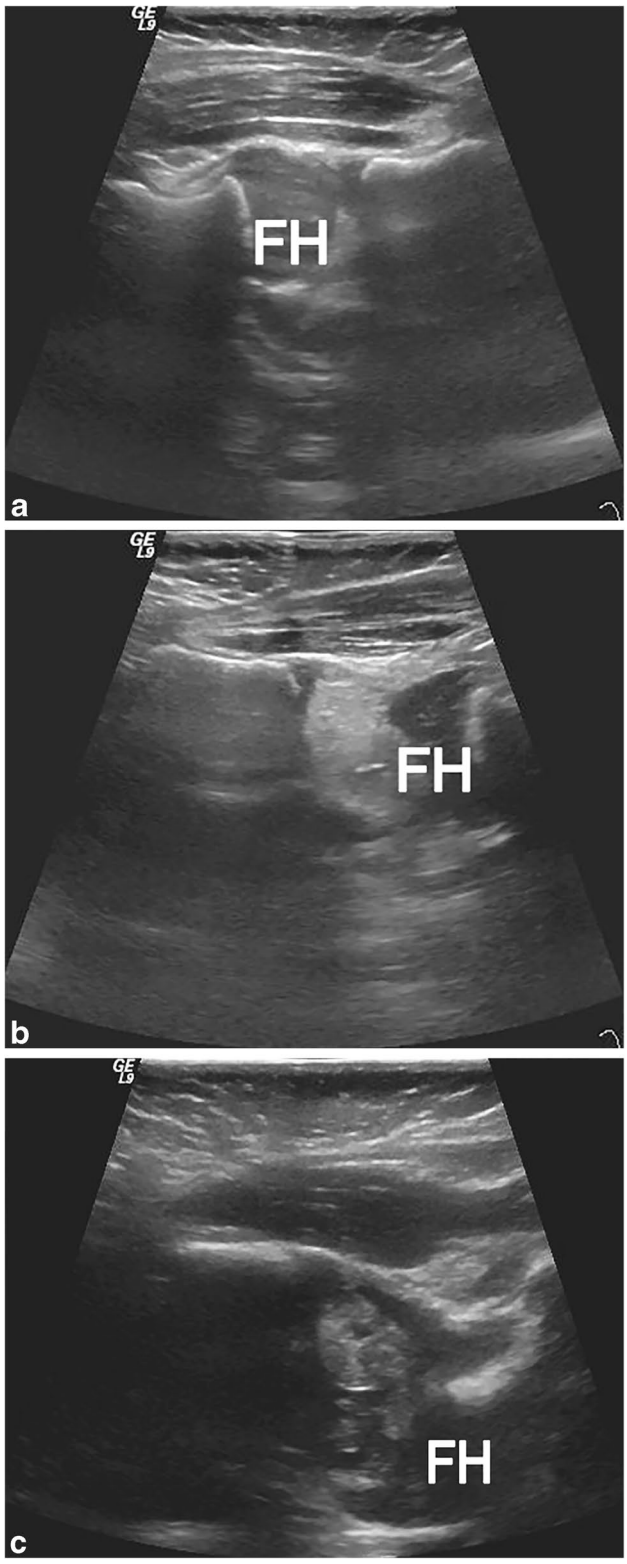

Fig. 6 Longitudinal ultrasound images (medial approach) of both proximal femurs in a 4.5-month-old boy with left dislocated developmental dysplasia of the hip. One week after closed reduction, the right femoral head is in the acetabular fossa with a PFD value of 2.0 mm (**a**). The left femoral head is in the acetabular fossa position and the PFD value is 7.6 mm (**b**). There are many abnormal hyperechoic masses filling the left acetabular fossa. Two weeks later, the left femoral head is again dislocated and now located posterolateral to the acetabular fossa. There are many abnormal hyperechoic masses filling the acetabular fossa (**c**). *FH* femoral head, *PFD* pubo-femoral distance

inguinal region. In such cases, the PFD is measured by drawing a vertical line inferiorly through the lateral edge of the superior pubic ramus and measuring the shortest linear distance between the vertical line and the medial edge of the ipsilateral femoral head (Fig. 1). When the femoral head is not in the acetabular fossa, the sonogram shows that the superior pubic ramus, the anterior margin of the femoral head and the femoral neck are not in the same horizontal plane on the medial cross section of the hip in the inguinal region. In these cases, the PFD is measured as the shortest linear distance between the outer posterior edge of the superior pubic ramus and the anterior margin of the ipsilateral femoral head (Fig. 1). This is because in the case of unsuccessful reduction, the femoral head is located outside or behind the acetabular fossa. Had the method in Fig. 1 been used for subluxed or dislocated hips, the PFD value would have been small or even negative, affecting the statistical results and not accurately reflecting the degree of femoral head displacement or dislocation.

During the follow-up of DDH reduction with medial hip ultrasound, the degree of reduction can be judged by comparing the PFD value with that measured on the contralateral normal side or with the normal range of PFD values in infants according to age (in months). Based on the latter, the reduction effect can be predicted by observing the change in the PFD value over time. A gradual decrease in the PFD value to within the normal range indicates that the treatment has been effective, whereas a gradual increase in the PFD value indicates that the condition requires further intervention to keep the hip reduced or to relocate the hip, as seen in some patients in the present study (Figs. 5 and 6).

Our study has several limitations. Firstly, it is limited by its retrospective design. Secondly, the results of advanced MRI before and after reduction were not available for correlation with the ultrasound imaging in our study. An abnormal hyperechoic mass in the acetabular fossa on ultrasound may be attributed to abnormal tissues limiting reduction; however, the anatomy or pathology blocking the reduction cannot be defined without MRI. Third, only the medial hip approach was feasible for scanning, as opposed to the conventional two-plane scanning from the lateral and anterior approaches. Fourth, the PFD was compared to that of the unaffected side; however, prediction of the change in PFD on subsequent scans (increase if unsuccessfully or decrease if successfully reduced) was not required because most of the femoral heads remained stable at 4 weeks post-reduction (other treatment methods are indicated if the hip cannot be reduced at 4 weeks post-reduction).

Finally, given that most of the available literature reports lateral hip ultrasound findings for DDH assessment, direct comparison with results of our study may not be possible.

There is limited publication of medial hip ultrasound data. We believe that this study contributes to research into the implications of medial hip ultrasonography. We believe ultrasound examination from the medial side is easy to perform and feasible in most centers. We believe that further studies are warranted to confirm its role in documenting post-reduction serial changes in PFD and determining the need for early intervention or likelihood of impending failure of reduction before irreversible damage can occur.

Conclusion

PFD values can be measured from the medial hip and compared with normal values in infants according to age to judge whether the femoral head is reduced and the degree of that reduction. Such imaging can be useful for predicting the early reduction outcome based on serial scans, and an increase in PFD may guide the timely adjustment of treatment. Ultrasound may not only be a tool for initial diagnosis but may also allow serial investigation documenting the results of reduction and supporting the prediction of outcomes.

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Declarations

Conflicts of interest None

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