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PEDIATRIC IMAGING
ORIGINAL ARTICLE

Comparison of morphologic and dynamic US methods in examination of the newborn hip

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PURPOSE
Comparison of morphologic and dynamic methods of hip ultrasonography (US) to differentiate normal from abnormal findings in the diagnosis of developmental dysplasia of the hip (DDH).

MATERIALS AND METHODS
A total of 6,800 hips in 3,400 infants were examined with US, using the morphological method of Graf, and the dynamic method of Harcke.

RESULTS
According to the Graf classification 81.47% of infants had Type 1 (normal hip), 10% Type 2a (physiologic immaturity), 2.44% Type 2b (acetabular dysplasia), 1.05% Type 2c (critical zone hip), 2.89% Type 3 (mildly dislocated), and 2.10% had Type 4 (dislocated) hips. Study in the transverse/neutral plane showed a normal relationship between the femoral head and the acetabulum in the 6,460 hips that were classified as Type 1–2c, that the hip was subluxated in 197 hips of Type 3, and was luxated in 143 hips of Type 4. Dynamic study with stress maneuver of the Type 1–2a hips showed that while 91.48% of the Type 1 hips (n = 5540) were stable and 8.52% were unstable, 92.37% of the Type 2a hips (n = 682) were stable and 7.63% were unstable. Dynamic study was not performed in cases that were diagnosed as Type 2b or worse. Follow-up US showed progression from Type 2a to Type 2b in 2.63% of Type 2a cases. Of the cases, 1.7% that were morphologically normal (Type 1) but unstable in their initial US examination, were revealed to be Type 3 later in the repeat US examination.

CONCLUSION
We believe that overtreatment and delayed treatment rates of DDH will be minimized by the use of both morphological and dynamic US methods in the evaluation of the newborn hip.

Key words: • *developmental hip dysplasia* • *congenital hip dysplasia* • *ultrasonography*

Although developmental dysplasia of hip (DDH) was first described more than two millennia ago, controversy continues even today with regard to the etiology, diagnosis, and treatment methods of this condition. Early diagnosis has become more important after it was discovered that dysplasia of the hip is not genetic, but developmental (1).

The most common methods of screening newborns for DDH are serial physical examinations of the hip using the Barlow and Ortolani maneuvers, and ultrasonography (US). Studies show that selective US screening (screening only infants with risk factors for DDH) has better results than universal screening (screening all infants). In the last twenty years, various methods have been developed for assesing the newborn hip by US. Among these, Graf's morphological method is widely used in Europe, and Harcke's dynamic method in the USA (2, 3). While Graf's method emphasizes the morphology of the hip, Harcke's dynamic method investigates its stability (4).

In our study, we performed hip US using both the morphological and the dynamic methods. We searched for acetabular instability and ligamentous laxity, which have an important role in the etiology of DDH. We also sought to ascertain whether every hip that is morphologically normal is stable in dynamic examination, and whether every hip that is dynamically unstable is abnormal.

Materials and methods

We performed US on 11,200 hips of 5,600 infants between March 2004 and May 2007 in our institution. Patients were referred to US for clinical suspicion of DDH, for having risk factors for DDH, or for follow-up US examination for infants with known DDH. Follow-up cases and those who were referred without clinical information were excluded. A total of 3,400 infants (1,258 male, 2,142 female; age range, 3 days–5 months; mean age, 7 weeks and 3 days) were included into the study. A total of 6,800 hips were examined. Patient history (including information about age, sex, family history, vaginal birth vs. Cesarean section, swaddling, and coexisting anomalies) and clinical findings were recorded. US examination of the infants who were suspected of having DDH by physical examination was performed immediately, while those with a normal physical exam but who were in the group at risk of DDH were examined in the 4th to 8th weeks of life.

Patients were not sedated, nor did they receive special preparation prior to the examination. Three radiologists experienced in pediatric hip US (P.K. with experience of 20 years, E.E. with experience of 6 years, and D.Ü. with experience of 10 years) performed the examinations with Shimadzu SD4 2200 and SD4 2200 x plus (Shimadzu Corporation, Tokyo, Japan). Whenever possible, each follow-up US examination was performed by the radiologist who performed the initial US. The evaluation was performed

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Table 1. Graf's classification (1)

* Type 1 is a mature hip with α >60°. It is divided into two subgroups: Type 1a, with β angle >55°; and Type 1b with β angle <55°.
* Type 2a is the physiologic immature hip in which α is between 50° and 59° in an infant younger than 12 weeks of age.
* If Type 2a morphology persists beyond 12 weeks, it is termed as Type 2b (acetabular dysplasia) where α is between 50° and 59°.
* Type 2c is a hip in the critical range (α = 43°–49°). It is divided into two subgroups: Type 2c stable and Type 2c unstable.
* In the Type D hip, the α angle is in the same range as in the Type 2c hip; however, the Type D is decentered, and has a β angle >77°.
* Type 3 and Type 4 hips are both decentered hips, with α <43° and β >77° in each. Determination of the position of the cartilaginous roof is crucial for differentiation of Type 3 and 4, which is pushed cranially in Type 3 hips, and caudally in Type 4 hips.
* Type 3 hip is further divided into two subgroups according to the echogenicity of the cartilaginous roof. In Type 3a hips, the roof is hypoechoic, whereas in the Type 3b hip, the hyaline cartilage is deformed, and appears hyperechoic.

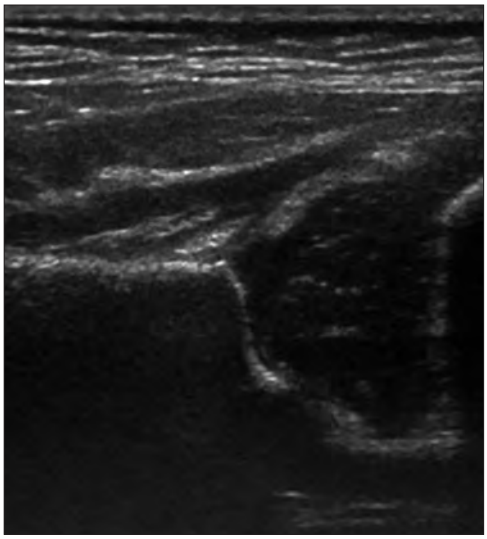

Figure 1. Normal hip in the coronal neutral US view.

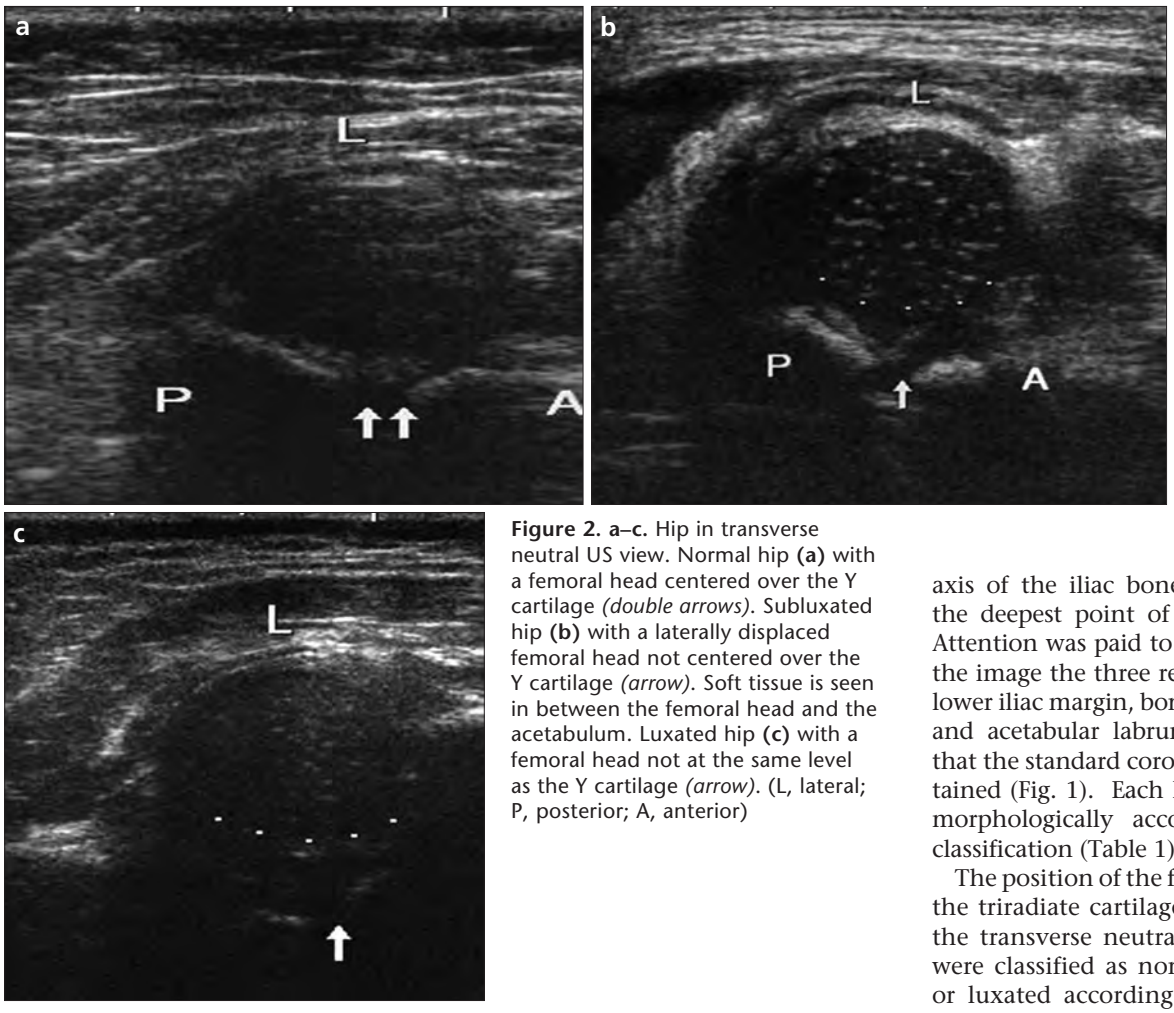

Figure 2. a–c. Hip in transverse neutral US view. Normal hip **(a)** with a femoral head centered over the Y cartilage *(double arrows)*. Subluxated hip **(b)** with a laterally displaced femoral head not centered over the Y cartilage *(arrow)*. Soft tissue is seen in between the femoral head and the acetabulum. Luxated hip **(c)** with a femoral head not at the same level as the Y cartilage *(arrow)*. (L, lateral; P, posterior; A, anterior)

in the transverse and coronal planes by a linear probe (band range, 5–7.5 MHz), through a lateral approach to the hip while the infant lay in a lateral decubitus position. For morphological analysis of the hip, transverse and coronal views were obtained with the leg either in neutral position or flexed at the hip and the knee. Great emphasis was given to assessment of the hip in the standard coronal plane, as described by Graf. This plane is parallel to the longitudinal axis of the iliac bone, and represents the deepest point of the acetabulum. Attention was paid to define clearly on the image the three reference points of lower iliac margin, bony acetabular rim, and acetabular labrum, to make sure that the standard coronal plane was obtained (Fig. 1). Each hip was classified morphologically according to Graf's classification (Table 1).

The position of the femoral head over the triradiate cartilage was assessed in the transverse neutral view. The hips were classified as normal, subluxated, or luxated according to the relationship between femoral head and the acetabulum in this view (Fig. 2).

Stability of the hip was assessed with the dynamic examination, which was performed by applying stress to the hip via Barlow's maneuver (by flexing and adducting the hip, and pushing the thigh posteriorly). Transverse flexion

Table 2. Distribution of hips according to the morphological evaluation of Graf's method, and the results of the study at transverse/neutral view

Number of hips	Graf's classification	Transverse/neutral view
5,540 (81.47%)	Type 1	Normal
682 (10%)	Type 2a	Normal
166 (2.44%)	Type 2b	Normal
72 (1.05%)	Type 2c	Normal
197 (2.89%)	Type 3	Subluxated
143 (2.10%)	Type 4	Luxated

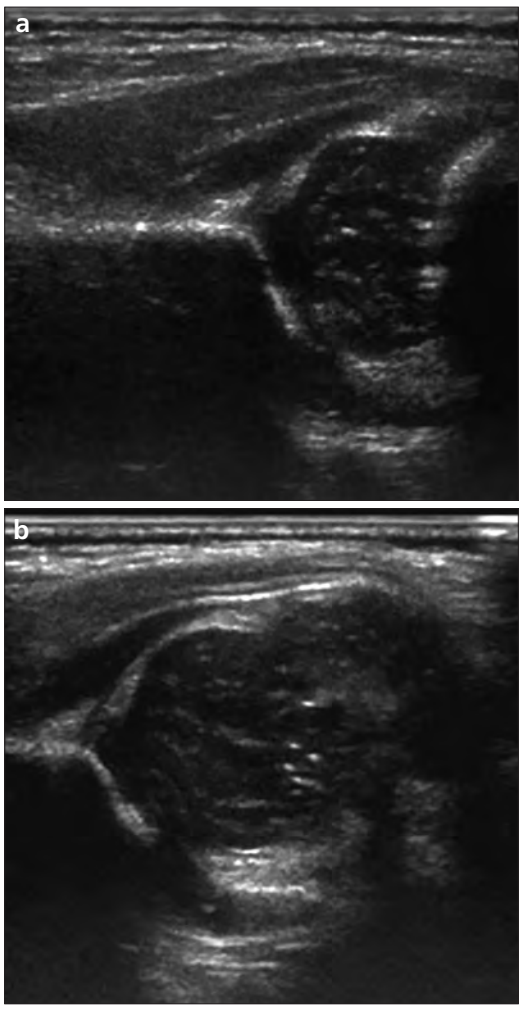

Figure 3. a, b. Hip that is morphologically normal but dynamically unstable. Normal hip in coronal neutral US view, $\alpha = 62°$ and $\beta = 50°$ **(a)**. Femoral head that is displaced laterally when stress is applied to the hip (unstable hip) **(b)**. When stress is applied, the beta angle increases from 50° to 70°.

and coronal flexion views were used for the dynamic examination. The hip was classified as stable or unstable according to this examination. Dynamic examination was not performed if the hip was classified as Type 2b (acetabular dysplasia) or worse according to Graf's classification by morphologic analysis.

Hips that had a normal relationship between the femoral head and the acetabulum in the transverse neutral view, (classified as Type 1 according to the Graf's classification), and that were found to be stable in the dynamic study, were accepted as normal and were not called back for a repeat US.

Hips that had a normal relationship between the femoral head and the acetabulum in the transverse neutral view [classified as Type 2a (physiologic immaturity) according to the Graf's classification], and that were found to be stable in the dynamic study were followed up by US at one-month intervals until the infants were 3–4 months old or had Type 1 morphology.

Hips that had a normal relationship between the femoral head and the acetabulum in transverse neutral view (classified as Type 1 or 2a according to the Graf's classification), and that were found to be unstable in the dynamic study, were followed up with US at one-month intervals. Hips that were stable by these US examinations were accepted as normal and had no treatment; however, if the instability persisted and a morphologic abnormality developed in these patients, the hip was classified according to the morphology, and treatment was given.

Hips that were classified as Type 2b (acetabular dysplasia) or worse by morphological analysis were also examined in the transverse neutral view to determine the relationship between the femoral head and the acetabulum, and were classified as normal, subluxated, or luxated according to this relationship. Dynamic study by applying stress was not performed in this group, whereas follow-up US examinations at one-month intervals were used to evaluate the response to treatment.

The study was approved by the instutional review board.

Results

In our study, the distribution of 6,800 hips according to the Graf's classification was as follows: 5,540 (81.47%) Type 1 (normal hip), 682 (10%) Type 2a (physiologic immaturity), 166 (2.44%) Type 2b (acetabular dysplasia), 72 (1.05%) Type 2c (critical zone), 197 (2.89%) Type 3 (mildly dislocated), and 143 (2.10%) Type 4 (dislocated).

Hips that were grouped as Type 1 and Type 2a–c according to Graf's classification (n = 6,460 hips) had the femoral head in its normal position, which appears as centered over the triradiate cartilage in the transverse neutral view, while all of the 197 hips that were grouped as Type 3 were subluxated, and all of those (n = 143 hips) that were grouped as Type 4 were luxated. Classification of the cases according to the Graf's method, and results of the study in the transverse plane and in neutral position are shown in Table 2.

Among the 5,540 hips that were grouped as Type 1 according to Graf's classification, 91.48% (n = 5,068 hips) were stable in dynamic examination while 8.52% (n = 472 hips) were unstable (Fig. 3). The age range of the cases with instability and Type 1 mor-

Table 3. Dynamic study of Type 1 and Type 2a hip dysplasia according to Graf's classification

Graf's classification	Number of hips	Stress maneuver findings	
		Stable	Unstable
Type 1	5,540	5,068 (91.48%)	472 (8.52%)
Type 2a	682	630 (92.37%)	52 (7.63%)

Table 4. Follow-up US results of the dynamically unstable Type 1 and Type 2a hips

Graf's classification	Unstable according to dynamic assessment	Follow-up US result	
		Type 1	Type 3
Type 1	472	464 (98.3%)	8 (1.7%)
Type 2a	52	52 (100%)	-

Figure 4. Type 3 hip in coronal neutral US view. Labrum *(open arrow)* is pushed cranially by the superolaterally displaced femoral head. Bony roof *(arrow head)* is severely deficient.

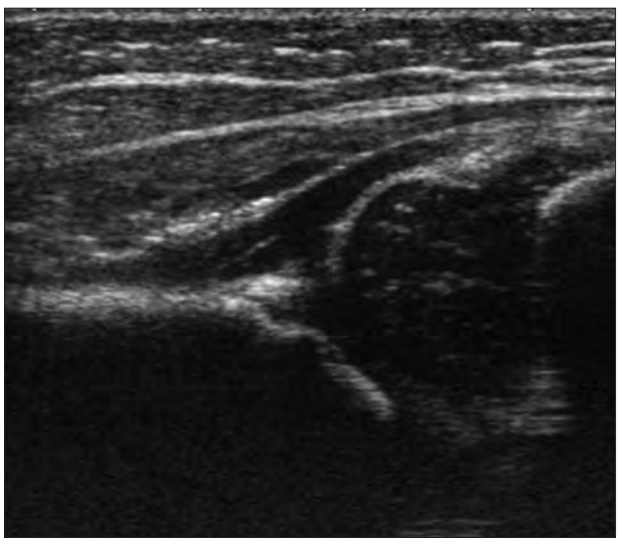

Figure 5. Type 4 hip in coronal neutral US view with a femoral head that is displaced superolaterally. Labrum and hyaline cartilage roof are pushed caudally by the displaced femoral head.

phology was 15–75 days. In the group classified as Type 2a (n = 682 hips), the rates of stability and instability with dynamic examination were 92.37% (n = 630 hips) and 7.63% (n = 52 hips), respectively (Table 3). So, among the 6,222 hips that were grouped as Type 1 or 2a and did not require treatment according to Graf's classification, 524 hips (8.42%) were found to be unstable in dynamic US examination.

These 524 hips (in a total of 300 infants; 224 with bilateral instability, and 76 with unilateral instability) were followed by US at one-month intervals without treatment. Of these 524 hips, 516 (in 224 infants with bilateral instability and 68 infants with unilateral instability) became stable in one or two months, were found to be stable with the dynamic method, and were classified as Type 1 according to the morphological assessment in the control US. In eight hips (eight infants with unilateral instability), stabilization did not occur, and six of them were diagnosed with Type 3 on morphological assessment at three months of age, while two of them had the same diagnosis at 4–5 months of age (Table 4). All of these eight hips were classified as Type 1 with the initial US examination. In other words, when we consider the hips that were diagnosed as Type 1 with the initial US (n = 5540), the incidence of late DDH was 8/5540 (0.14%).

Six hundred and eighty-two hips which that were diagnosed as Type 2a with the initial US examination had follow-up examinations with one-month intervals, and in 18 of them (18/682, 2.64%) no stabilization was observed. They underwent treatment with the diagnosis of acetabular dysplasia (Type 2b).

In our study, abnormality that required treatment was found in a total of 578 hips (8.5%). Of these, 166 hips (2.4%) were classified as Type 2b (acetabular dysplasia), 72 hips (1%) as Type 2c (critical zone), 197 hips (2.8%) as Type 3 (mildly dislocated) and 143 hips (2.1%) as Type 4 (dislocated) (Figs. 4, 5).

Discussion

Physical examination cannot reliably diagnose dysplastic hips, and may also miss unstable or even dislocated hips. In addition, it may result in overtreatment because of false-positive findings (5, 6). According to the litera-

ture, US is the most reliable method in the diagnosis of DDH (7–9). The greater proportion of cartilage in the acetabulum and femoral head in the newborn increases the sensitivity of US (4, 10). Different techniques for examination of the newborn hip by US have been described. Among the others, two methods are widely accepted: The morphological method, which was developed by Graf (1), and the dynamic method, which was developed by Harcke and Grissom (11).

Graf's method requires several measurements of angles. In addition, obtaining the correct sectional plane requires skill and experience; hence, the expertise of the operator has a significant effect on the results of the study. Because of the importance of accurate diagnosis of instability in the newborn hip (12), researchers have sought alternative methods, which are more practical, easy to learn, and less operator-dependent.

Soon after Graf's publication of the morphological method, Harcke and Grissom developed a different technique, the dynamic method. This method focuses on the position of the femur and stability of the hip to discern the clinical significance of "sonographic" DDH (10, 11). Similar methods have been developed by other researches. For example, Morin et al. classified hips as normal, indeterminate, and abnormal according to the proportion of the femoral head coverage by acetabulum (13). Keller et al. applied the Barlow maneuver to demonstrate instability of the hip in the transverse plane (14).

In opposition to the researchers who defend the importance of detection of the hip instability with dynamic US methods, Graf suggests that with dynamic examination, physiological variations due to age cannot be distinguished from the real dysplasia (1).

The complex morphology of the newborn hip, and its dynamic maturation process makes it diffucult to evaluate by US. In addition, differences in interpretation between the various methods of hip US cause confusion of terminology, and result in overlap of normal and abnormal findings; difficulties in diagnosis, follow-up, and treatment; and overtreatment in some cases (12, 15).

In our study, in order to determine which hips are normal and which are abnormal, and which cases should be followed up or treated, we compared Graf's method of morphological analysis of the hip and Harcke's dynamic method. We also tried to determine if every hip that is morphologically normal is stable in dynamic study, and if every hip that is unstable in dynamic study is abnormal or will become abnormal morphologically.

Review of the literature reveals few comparative studies of neonatal hip morphology and instability. A study published by Finnbogason et al. (16) compared physical examination, Graf's method, and the dynamic method. In this study, 10% of cases were reported as unstable with dynamic study, 14% unstable with physical examination, and 20% as immature with Graf"s method. They stated that the follow-up rate due to indeterminate examination results increases when Graf's technique is used. In our study, follow-up due to instability was 8.42%, and follow-up due to physiologic immaturity (Type 2a morphology) was 10%. In other words, the follow-up rates of the two techniques were similar.

In a study comparing dynamic US with the clinical stress test, Finnbogason et al. (17) reported a treatment rate of 0.85% based on physical examination, and 0.49% based on dynamic US. These authors emphasized that the rate of overtreatment was higher when determined by physical examination. A study by Rosendahl et al. (18), which compared physical examination and US findings, found that reliance on US findings tended to cause overtreatment. Review of the literature shows many controversial or opposing studies concerning DDH diagnosis, follow-up, and treatment. The explanation of this disagreement may be false interpretation of the variations of the normal physiological development as a pathologic process of the hip in some studies, as well as differences of terminology between radiologists and clinicians, and differences of physical examination and hip US standards.

In the study of Rosendahl et al. (19), 91% of hips in infants with normal hip morphology were found to be unstable, and 49% of the unstable hips were found to have normal morphology. In this study, it was concluded that unstable hips that have normal morphology stabilized spontaneously, and that morphology was an important diagnostic criterion. In a study of infants who were 2–4 weeks old and had normal hip morphology and bilateral or unilateral hip instability, half were treated with Frejka's pillow, and the other half were not treated (20). Follow-up ultrasounds did not show a significant difference between the two groups, and it was concluded that sonographic instability in morphologically normal or immature hips had no clinical significance.

In our study, infants with normal hip morphology and bilateral or unilateral hip instability did not undergo any treatment, but had US follow-up. In 1.53% of these, the abnormility persisted, and Type 3 morphology developed during follow-up. These were considered as 'late DDH' cases in the present study, and their incidence was found to be 0.14%, which is consistent with the rate of 0.17% that is reported as late DDH incidence in the literature (21). We believe that unstable hips with normal morphology do not require immediate treatment because spontaneous recovery takes place in the majority of cases; however, they should have follow-up US examinations. In as many as 1.7% of them, as demonstrated in the present study, late DDH may develop.

Infants with Type 2a hips are younger than three months old and are expected to complete their hip development spontaneously and become normal by the time they reach three or four months of age (18). However, in a minority of Type 2a cases, maturation of the hip is not completed by four months of age (4, 5). These should be considered to Type 2b (acetabular dysplasia), which requires treatment (22). Therefore, Type 2a hips should be followed by US until hip maturation takes place and Type 1 morphology develops. In the present study, maturation of the hip did not occur in 2.63% of the Type 2a hips. These hips became Type 2b. This rate was found to be 3.3% in a study by Rosendahl et al. (18). In another study, the frequency of Type 2a was reported as 11.8%. In 1.78% of these cases, progression to Type 2b was detected (23).

In the literature, a relationship was found between hip instability and reduced acetabular depth in the newborn in a comparative study of physical examination and morphological US (15). In the present study, 7.63% of Type 2a hips were found to be un-

stable while the rate of instability in Type 1 morphology was 8.52%. On the bases of this observation, we believe it can be said that there is no correlation between delay of maturation and instability.

Regardless of the technique used, hip US is an operator-dependent modality in which experience of the operator has a great influence on the results of the examination. We believe this factor is the main limitation of the present study, as in other studies performed by US.

In conclusion, follow-up US showed that instability persisted in eight subjects (1.7%) that were diagnosed with Type 1 (normal hip) with the initial US examination and had the diagnosis of Type 3 (mildly dislocated) at follow-up. This observation led us to the following conclusions:

1. We should perform a dynamic study with stress maneuvers on every hip that is morphologically normal.
2. Hips that are morphologically normal and stable in dynamic study are considered to be "sonographically normal" and do not require follow-up US. Follow-up clinical examinations until one year of age are recommended in these cases (5, 9).
3. Detection of instability in Type 1 or Type 2a hips (which has an incidence of 8.42% in the present study) does not indicate an abnormality that requires immediate treatment. Such hips should have follow-up US examinations until they become stable according to the dynamic study.
4. In order to minimize the number of "late DDH" cases, persistent instability of the hip even with normal morphology should be followed by US.

References

1. Graf R. The use of ultrasonography in developmental dysplasia of the hip. Acta Orthop Traumatol Turc 2007; 41 Suppl 1:6–13.
2. Synder M, Harcke HT, Domzalski M. Role of ultrasound in the diagnosis and managment of developmental dysplasia of the hip: an international perspective. Orthop Clin North Am 2006; 37:141–147.
3. Richard B. Ultrasound in pediatric musculoskeletal disease: techniques and applications. Radiol Clin North Am 2001; 39:597–618.
4. Wientroub S, Grill F. Current concepts review: ultrasonography in developmental dysplasia of the hip. J Bone Joint Surg 2000; 82A:1004–1018.
5. Aronsson DD, Goldgberg MJ, Kling TF, Roy DR. Developmental dysplasia of the hip. Pediatrics 1994; 94:201–208.
6. Holen KJ, Tegnander A, Bredland T, Johansen OJ, Sæther OD, Eik-Nes SH, et al. Universal or selective screening of the neonatal hip using ultrasound? A prospective, randomized trial of 15,529 newborn infants. J Bone Joint Surg Br 2002; 84:886–891.
7. Bar-On E, Meyer S, Harari G, Porat S. Ultrasonography of the hip in developmental hip dysplasia. J Bone Joint Surg Br 1998; 80:321–324.
8. Baronciani D, Atti G, Andiloro F, et al. Screening for developmental dysplasia of the hip: from theory to practice. Collaborative Group DDH Project. Pediatrics 1997; 99:5e.
9. French LM, Dietz FR. Screening for developmental dysplasia of the hip. Am Fam Physician 1999; 60:177–184, 187–188.
10. Harcke HT, Grissom LE. Pediatric hip sonography: diagnosis and differential diagnosis. Radiol Clin North Am 1999; 37:787–796.
11. Harcke HT, Grissom LE. Performing dynamic sonography of the infant hip. AJR Am J Roentgenol 1990; 155:837–844.
12. Engesaeter LB, Wilson DJ, Nag D, Benson MKD. Ultrasound and congenital dislocation of the hip. The importance of dynamic assessment. J Bone Joint Surg Br 1990; 72:197–201.
13. Morin C, Harcke HT, MacEwen GD. The infant hip: real-time US assessment of acetabular development. Radiology 1985; 157:673–677.
14. Keller MS, Weltin GG, Rattner Z, Taylor KJW, Rosenfeld, NS. Normal instability of the hip in the neonate: US standards. Radiology 1988; 169:733–736.
15. Roposch A, Wright JG. Increased diagnostic information and understanding disease: uncertainty in the diagnosis of developmental hip dysplasia. Radiology 2007; 24:355–359.
16. Finnbogason T, Jorulf H, Söderman E, Rehnberg L. Anterior dynamic ultrasound and Graf's examination in neonatal hip instability. Acta Radiol 2008; 49:204–211.
17. Finnbogason T, Jorulf H, Söderman E, Rehnberg L. Neonatal hip instability: a prospective comparison of clinical examination and anterior dynamic ultrasound. Acta Radiol 2008; 49:212–219.
18. Rosendahl K, Markestad T, Lie RT. Congenital dislocation of the hip: a prospective study comparing ultrasound and clinical examination. Acta Paediatr 1992; 81:177–181.
19. Rosendahl K, Markestad T, Lie RT. Ultrasound in the early diagnosis of congenital dislocation of the hip: the significance of hip stability versus acetabular morphology. Pediatr Radiol 1992; 22:430–433.
20. Reikerås O, Kristiansen LP, Gunderson R. Ultrasonography of the infant hip: the significance of provokable insitability with normal morphology. Orthopedics 2002; 25:833–835.
21. Finne PH, Dalen I, Ikonomou N, Ulimoen G, Hansen TW. Diagnosis of congenital hip dysplasia in the newborn. Acta Orthop 2008; 79:313–320.
22. Donaldson JS, Feinstein KA. Imaging of developmental dysplasia of the hip. Pediatr Radiol 1997; 44:591–614.
23. Dogruel H, Atalar H, Yavuz OY, Saylı U. Clinical examination versus ultrasonography in detecting developmental dysplasia of the hip. Int Orthop 2008; 32:415–419.