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Does a Normal Hip Ultrasound at 3-6 Months of Age Predict a Normal X-ray?

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Abstract

Objective: Ultrasound (US) may be used to diagnose/monitor developmental dysplasia of the hip (DDH) prior to femoral head ossification, after that, radiographs (XR) may become a better choice. The objective of this study was to compare US to XR performed on the same day for diagnosis or monitoring of DDH in patients 3 to 6 months of age.

Methods: 92 patients (183 hips) ages 3 to 6 months who were seen for hip screening for DDH were retrospectively reviewed. All patients had a same-day hip ultrasound and plvis radiograph. Alpha angle, hip stability, femoral head coverage, acetabular index (AI), IHDI grade, and break in Shenton's line were recorded and used to diagnose the hip as normal or dysplastic.

Results: 17.5% of hips were diagnosed with DDH based on XR, 12% of hips were diagnosed with DDH on US. Thirteen hips were read as normal on US but dysplastic on XR. Using XR as the definitive diagnosis, US had sensitivity of 59% and specificity of 98%. Using US as the definitive diagnosis, XR had sensitivity of 86% and specificity of 92%.

Conclusion: In the 3-6 month age group, US alone may under-diagnose hip dysplasia and be inadequate to guide treatment decisions. In this age group, we suggest that pelvis radiographs be used when deciding to either initiate or conclude DDH treatment based on the higher sensitivity of the exam.

Introduction

Developmental dysplasia of the hip (DDH) encompasses a wide range of pediatric hip disorders from malformation of the acetabulum to complete dislocation of the hip [1-4]. The incidence of DDH has been reported as 1-7% of newborns [5], although reported incidences can vary widely in different populations [6-8]. The American Academy of Pediatrics Clinical Practice guidelines recommends that patients with positive physical exam findings be referred to an orthopedic surgeon for further clinical and radiographic evaluation [1].

Infants less than three months of age with risk factors and/or physical exam concerning for DDH are typically evaluated with ultrasonography (US), as the hip structures in this age group are almost entirely cartilaginous and not well visualized on pelvis radiographs (XR). As the femoral head ossifies, it creates an acoustic shadow on US that obscures the portion of the acetabulum behind it, making US both difficult to perform and less accurate [9,10]. During this time period, physicians often transition from US to XR to diagnose and track the progression of DDH. However, the timing for this transition is often debated. Many advocate for the use of ultrasound as the sole diagnostic test up to 6 months and some up to 2 years of age in order to minimize radiation exposure to the infant [11,12].

A combination of static and dynamic ultrasound as described by Graf and Harke in the 1980's is commonly used in the pediatric orthopedic office to diagnose and monitor the progress of DDH in infants [13,15,16]. Graf characterized the alpha angle, which defines the slope of the superior portion of the acetabulum [9]. An alpha angle over 60 degrees is considered normal and a smaller angle is considered acetabular dysplasia [17]. Dynamic ultrasound is an excellent test for hip instability. However once the hip has been stabilized, there is debate as to whether or not ultrasound is adequate for diagnosis of residual acetabular dysplasia.

Pelvis radiographs are used to gauge acetabular morphology, femoral head ossification, and dysplasia [3]. The acetabular index is the angle formed by Hilgenreiner's line and the slope of the acetabulum on pelvis XR [18]. Larger angles correlate with more dysplasia [18,19]. XR can also be used to measure the International Hip Dysplasia Institute (IHDI) grade, which uses the central point of the proximal femoral metaphysis as a reference point [10]. Similar to the Tönnis method [14], the hip is divided into four quadrants by Hilgenreiner's line (horizontal line through the triradiate cartilages) and Perkin's line (vertical line perpendicular to Hilgenreiner's and passing through the lateral edge of the acetabulum) and then an additional diagonal line drawn at 45 degrees from the junction of Hilgenreiner's line [10]. Grade I is considered normal; the center of the proximal femoral metaphysis is located in the inferomedial quadrant. In grades II-IV, the femoral head is progressively more lateral and then proximal; higher grade correlates with worsening dysplasia.

Traditionally, our institution used ultrasound to evaluate infantile DDH from birth to age three months. At age three months, we typically switch to x-ray. However, due to a presentation at a national conference (American Academy of Orthopedic Surgeons - 2017, San Diego, CA) on the topic of infantile DDH, some of our physicians began to question the use of x-ray in the three-to-six-month age group. These physicians began to order ultrasound, as well as x-ray, in the three-to-six-month age group as they were more familiar with x-ray in this age group, and this would serve as a way to ultimately transition from x-ray towards the use of ultrasound.

We have noted both in the literature and in our practice patients who have a normal ultrasound but later are diagnosed with DDH on

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XR. It is unclear whether these patients developed dysplasia after the initial US or if the dysplasia was present but the US was not sensitive enough to diagnose it. The purpose of this current study was to directly compare XR to US in infant's age 3 to 6 months to better clarify the efficacy of each and to determine appropriate management of these patients.

Materials and Methods

Following IRB approval, we conducted a retrospective review of 92 patients and 183 hips ages 3 to 6 months who were being evaluated or treated for DDH at a single institution between November 2017 and May 2019. All patients who had a hip ultrasound and pelvis radiograph on the same day were included in the study. One patient did not have bilateral ultrasound, which excluded one hip from this study. All ultrasounds were performed by a single ultrasound technician with over 20 years of experience working solely in orthopedic clinics treating DDH (Figure 1). Each hip XR and US was measured by two fellowship trained, pediatric orthopedic surgeons, blinded to patient identifying information and to the result of the other study (XR or US). Pelvis radiographs were obtained in a standardized position to ensure accurate anterior-posterior images without rotation or tilt.

On US, dynamic stability was assessed on both coronal and transverse views. Any instability was classified as DDH. Instability was defined as a change in femoral head coverage, as evaluated on ultrasound, with stress on the hip joint. Alpha angle was measured on the coronal view on US with the hips flexed to approximately 90° and in neutral abduction (Figure 2a). An alpha angle greater than 60° were considered as normal and an angle less than 60° were considered as dysplastic. Beta angle was not used in this study as the authors felt that there was too much inter- and intra-rater variability and none of the authors use this measure in clinical practice. Acetabular index (Figure 2b), IHDI grade and presence/absence of the ossific nucleus were determined using the pelvis radiograph. Determination of DDH on XR was decided based on acetabular index and the IHDI grade (which includes femoral head coverage/subluxation/dislocation). Hips were classified as normal or dysplastic based on their measurements compared to the accepted values for their sex, specific age, and laterality. See Table 1 for details of these values [13,14]. Subjects with an IHDI grade greater than I were classified as dysplastic, regardless of their acetabular index. Hips with disagreement between the two observers were re-reviewed to determine a consensus regarding the diagnosis. A subset of 24 hips were re-measured greater than two weeks later to evaluate intra-rater reliability.

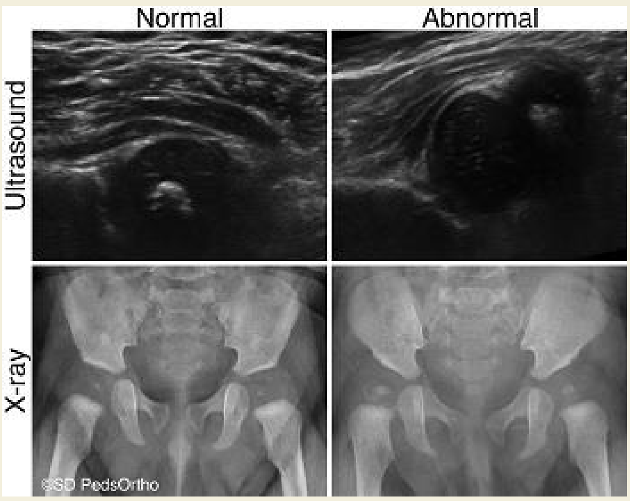

Figure 1: Ultrasound and radiograph images from typical normal patients and patients with developmental dysplasia of the hip.

Statistical Analysis

Basic descriptive statistics are reported. The unit of analysis was the hip. All continuous data was evaluated with the Shapiro-Wilk test of normality and found to be non-normally distributed. This data was evaluated with the Mann-Whitney test. Gwet's agreement coefficient 1 (AC1) adjusted kappa was used for evaluating inter-modality agreement in diagnosing DDH between XR and US due to the disproportionate number of normal hips. Kappa values were considered excellent if between 0.8-1.0, good between 0.6-0.79, moderate between 0.4-0.59, and fair between 0.21-0.39. The intra class correlation coefficient (ICC) was used to evaluate inter- and intra-rater reliability of alpha angle and acetabular index. No a priori power analysis was performed. All analysis was conducted using SPSS (version 26; IBM, New York, USA). Statistical significance was defined as $p<0.05$.

Results

One hundred eighty-three hips in 92 patients were studied. The majority of patients were female (67%). The mean age of the cohort was 4.2±0.9 months (range: 3.0 to 5.8 months). The ossific nucleus was present in 80 hips (44%). Cohort characteristics can be found in Table 2. Inter-observer reliability was found to be higher when measuring acetabular index (ICC=0.820) than when measuring alpha angle (ICC=0.654). The full ICC distribution can be found in Table 3.

After classifying the 183 hips independently, our two reviewers

Table 1: Radiographic classification.

Image type (measurement)	Sex	Age in mos	Side	Normal	DDH
	Female	3 & 4	R	<31°	≥31°
			L	<33°	≥33°
		5 & 6	R	<27°	≥27°
			L	<29°	≥29°
	Male	3 & 4	R	<28°	≥28°
			L	<29°	≥29°
		5 & 6	R	<24°	≥24°
			L	<27°	≥27°
Ultrasound (alpha angle)	M or F	3 to 6	R or L	≥60°	<60°

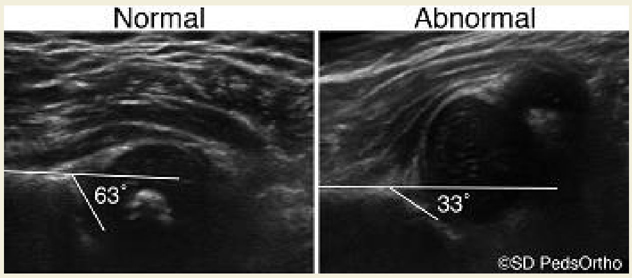

Figure 2a: Alpha angle measurement on typical normal hip and abnormal hip.

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had the same interpretation for 92% of XR images and 87% of US images. Both reviewers independently diagnosed 128 hips as normal on both XR and US. There were 36 hips (14 XRs and 22 USs) with some discrepancy between the two reviewers on at least one of the measurements. After inter- and intra-observer reliability was calculated, the two reviewers were again blinded to patient information and prior reads for this subset of 36 hips and interpreted the imaging together to determine a consensus. After the consensus, comparisons could be made between US and XR. Nineteen hips (10.4%) were classified as dysplastic on both US and XR. 148 hips (80.9%) were classified as being normal on both US and XR. Thirteen hips (7.1%) were classified as being dysplastic on XR but normal on US (Figure 3). Three hips (1.6%) were classified as being dysplastic on US and normal on XR. Three hips (1.6%) with an acetabular index that was normal for their age/sex were classified as dysplastic based on an IHDI grade of II, all three had an abnormal ultrasound and a break in Shenton's line.

Of the 13 hips that were classified as being dysplastic on XR, but not on US, all were IHDI grade I, with Shenton's line intact. Six of these 13 hips had an absent ossific nucleus. The age range for these hips was 3.1 to 5.6 months (mean: 4.4±0.9 months). Of the 22 hips diagnosed with DDH on US, three were ruled as normal on XR. Two of these hips were classified as mild DDH on US with alpha angles of 53° and 56°. The remaining hip had an alpha angle of 43°, with an acetabular index of 14°. These hips ranged in age from 3.2 months to 3.6 months. All three were IHDI grade I with an absent ossific nucleus. Using XR as the definitive diagnosis, US had sensitivity of 59% and specificity of 98%. Using US as the definitive diagnosis, XR had sensitivity of 86% and specificity of 92%.

Not surprisingly, hips with an ossific nucleus present were found to be older (4.6±0.8 months) on average than subjects with an absent ossific nucleus (3.9±0.8 months) (p<0.001). Six hips with a present ossific nucleus were found to have DDH via US and all six were also noted to have DDH via XR. Seven additional hips with a present ossific nucleus were found to have DDH via XR but not on US.

Table 2: Cohort characteristics.

Age (months)	Mean±SD	4.2±0.9
	Range	3.0 to 5.8
Sex [n (%)]	Male	60 (33%)
	Female	123 (67%)
Acetabular Index (°)	Mean±SD	24.8±5.4
	Range	14 to 47
Alpha Angle (°)	Mean±SD	67.6±7.1
	Range	41 to 83
Ossific Nucleus [n (%)]	Present	80 (44%)
	Absent	103 (56%)
	I	175 (96%)
	II	6 (3%)
	III	2 (1%)
	IV	0 (0%)
Shenton's Line [n (%)]	Intact	175 (96%)
	Broken	8 (4%)
Treatment [n (%)]	None	89 (49%)
	Treated Prior*	66 (36%)
	Treatment Initiated**	28 (15%)

*Treatment began prior to study film,
**Treatment initiated at the clinic visit the study film was ordered during

Discussion

In a study by Imrie et. al, 300 patients referred for hip evaluation due to breech birth position were followed for development of dysplasia [20]. At the initial 6-week screening, 27% of the patients had an abnormal US. Of the remaining 73% with initial normal US, 29% had evidence of dysplasia at their 4 to 6-month follow-up and subsequently underwent treatment for DDH. This subset of later diagnoses can be explained by the patients either developing dysplasia after the initial ultrasound or that the initial ultrasound was simply not sensitive enough to diagnose it. The purpose of our current study was to compare the efficacy of US to XR with regards to diagnosis of DDH in infants 3 to 6 months of age. Our study found that US diagnosed fewer patients (12.0%) with DDH compared to XR (17.5%). The sensitivity of US was low and the specificity was high.

A test with high specificity will correctly identify hips that do

Table 3: Inter- and intra-observer reliability.

		ICC	Lower	Upper	Sig.
Inter-observer reliability	Alpha (US)	0.654	0.562	0.730	p < 0.001
	AI (XR)	0.820	0.766	0.862	p < 0.001
Intra-observer reliability	Alpha (US)	0.656	0.335	0.837	p < 0.001
	AI (XR)	0.714	0.449	0.864	p < 0.001

AI = Acetabular index

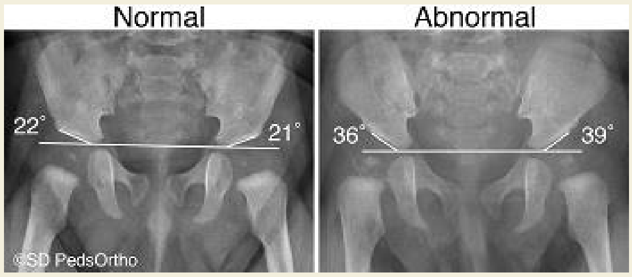

Figure 2b: Acetabular index measurement on a typical normal and abnormal radiograph.

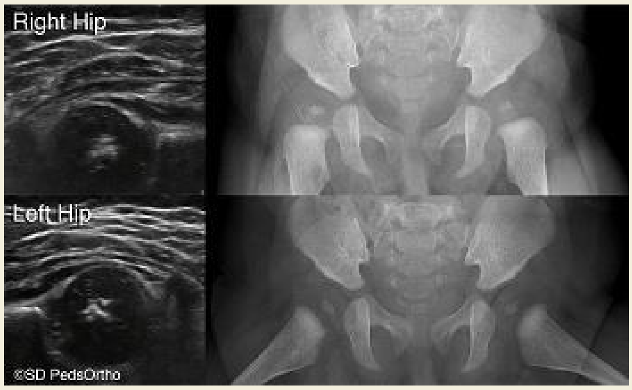

Figure 3: Sample patient that had hip ultrasounds that were considered normal and pelvis radiographs that were considered abnormal on the same day.

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not have DDH. Conversely, a test with high sensitivity will correctly identify hips that do have DDH. Our finding that US have a high specificity of 98% indicates that a positive US is sufficient to diagnose DDH in this age group. The low sensitivity of 59% indicates that a negative US is insufficient to rule out DDH in this age group. US done at our institution for evaluation of DDH in 3 to 6-month infants had a higher number of false negatives than false positives. A false negative is potentially troublesome when US is used as the only diagnostic and evaluation tool for DDH. If a patient with DDH is not properly diagnosed they may not be treated or may have their treatment stopped prior to complete resolution of DDH.

In this study, ultrasounds that were read as dysplastic correlated moderately well with XR so we recommend treating for DDH based on US that shows instability and/or dysplasia, knowing that a small percentage of patients will be over-treated with a Pavlik or abduction brace which has a very low complication risk. A normal ultrasound in the 3-6 month age group does not rule out residual acetabular dysplasia and may lead to under treatment of DDH if it is the only diagnostic tool used. Under treating DDH puts the child at risk of early hip degeneration and osteoarthritis. We therefore recommend a pelvis radiograph to confirm normal hip development before releasing the infant from care/treatment. XR has better inter and intra-rater reliability and is not as operator-dependent or subjective as US.

Previous studies have made differing recommendations on when radiographs are the most appropriate modality for assessing DDH [17,19,21-23]. It is generally agreed that radiographs become more reliable after 4 months of age and the American Academy of Pediatrics (AAP) has stated that US and XR seem to be equally effective between 4 to 6 months of age as the femoral head is ossifying [1]. Many orthopedists predominantly utilize ultrasound until 6 months of age [10,11]. However, ultrasound is very operator dependent and reading ultrasounds is quite subjective. The variation in technique and evaluation may lead to under or over diagnosis of dysplasia by ultrasound. The AAP has stated that there is no “gold-standard” for diagnosis of DDH at any point in time and overall there is a paucity of research to help provide data-driven treatment guidelines [1].

Other studies have directly compared US and XR. Spaans et. al analyzed US and XR performed on the same day in 74 infants being treated for stable DDH [24]. Counter to our results, they found that US was able to diagnose DDH in more hips than XR. However, similar to us, they found acetabular index and alpha angle to be poorly correlated. Terjesen et. el also compared US to XR conducted on the same day in 312 consecutive hips [25]. After excluding normal, subluxated, and dislocated hips, they also found poor correlation between US and XR measurements. Similar to our study, radiographs were able to diagnose DDH in more hips than ultrasonography. In seven of the fifteen hips with radiographic dysplasia, there were normal US findings. All patients with abnormal US also had abnormal XR measurements.

Ultrasound remains an extremely valuable imaging modality for dynamic assessment of the hip, especially in the first few months of life when the hip structures are almost entirely cartilaginous. The combination of static and dynamic US is a valuable clinical tool for the diagnosis and monitoring of DDH without any radiation risk to the infant. US has been shown to be much better than XR at diagnosing instability of a hip and should be used until the ultrasound is read as normal or the femoral head is too ossified to allow good visualization with US. US remains our primary imaging modality in patients less than 3 months of age and older if US remains abnormal.

A primary limitation of this study is the prevalence of disease in this study cohort. Despite the large sample size (183 hips at risk for or being treated for DDH), there were a small number of hips diagnosed with DDH (35 hips or 19%) on either XR or US at the time point where they had both done on the same day. A cohort with a larger prevalence of DDH could influence our sensitivity and specificity. However, our cohort reflects the actual distribution of DDH among subjects seen in our orthopedic clinic for hip evaluation or treatment during this time period. In addition, this smaller sample of diseased hips prevented further subset analysis based on potential confounders such as dysplasia severity and current or prior treatments. We understand that this does not offer a complete scope of the process involved in the diagnosis of DDH, but it is our hope that this offers a compelling platform on which to build further research and highlights the importance of radiographic imaging in the diagnosis and treatment of DDH.

In conclusion, our data indicates that in infants age 3 to 6 months, US missed 13 (41%) of the hips where DDH was diagnosed by XR performed on the same day. If only US had been done for these 13 hips, they may have been undertreated for DDH that was noted on XR. We recommend that in the 3 to 6 month age group, treatment decisions be confirmed by using standard pelvic radiographs. If ultrasound is normal in a high-risk infant with an unossified ossific nucleus, we have them return to clinic around 6 months of age to confirm the normal diagnosis with XR before releasing them from clinic. If DDH is found on XR at 6 months, there is still adequate time to treat DDH with a harness or abduction brace.

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