HSSJ (2019) 15:153–158
DOI 10.1007/s11420-018-09657-9

HSS Journal®

ORIGINAL ARTICLE

Ultrasound Is an Alternative to X-ray for Diagnosing Developmental Dysplasia of the Hips in 6-Month-Old Children

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Received: 17 May 2018/Accepted: 21 November 2018/Published online: 22 February 2019

Abstract *Background:* Infants previously treated for developmental dysplasia of the hips (DDH) are routinely imaged with ultrasound initially and reimaged with an anteroposterior (AP) pelvis X-ray at 6 months of age to assess for dysplasia. It has become convention to transition from ultrasound to AP X-ray at 6 months of age, but no study has demonstrated that ultrasound is inadequate at this age. *Question/Purpose:* The purpose of this study was to confirm that ultrasound for the 6-month DDH evaluation is a feasible alternative to the standard X-ray. *Patients and Methods:* Thirty-one 5- to 7-month-old infants undergoing AP pelvis X-ray related to previous Pavlik harness treatment for DDH or to a history of breech presentation were prospectively enrolled. All patients were imaged with an AP pelvis X-ray and bilateral hip ultrasounds. Three senior orthopedic surgeons unfamiliar with the patient histories evaluated both types of imaging for standard measures of hip dysplasia, including acetabular index (AI), alpha angle, and bony rim percent coverage of the femoral head. Pearson correlation coefficients were calculated for the X-ray and ultrasound measures. *Results:* Good quality ultrasound images were obtained in all patients, despite the presence of the ossific nucleus in 66% of the hips. All three reviewers correctly diagnosed the one dislocated hip via both X-ray and ultrasound. There were no false negatives on ultrasound, and none of the patients with negative ultrasounds required treatment during the mean 26 months of follow up. An increased AI on X-ray was correlated with lower percent coverage of the femoral head on ultrasound. *Conclusions:* Ultrasound is a technically feasible DDH imaging modality that can be used as an alternative to X-ray for 6-month-olds.

Keywords developmental dysplasia of the hip · DDH · ultrasound · pediatrics

Level of Evidence: Level II: Diagnostic Study

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11420-018-09657-9) contains supplementary material, which is available to authorized users.

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Introduction

Developmental dysplasia of the hip (DDH) is one of the most common orthopedic conditions in infancy. It is estimated that 1 in 1000 US children is born with a dislocated hip, and 10 in 1000 US children are born with dysplasia or hip subluxation [5].

The potential consequences of untreated DDH are serious, including abnormal gait, osteoarthritis, and hip pain at a relatively young age. Untreated DDH is one of the most common causes of degenerative joint disease requiring hip arthroplasty in patients younger than 60 years old [7]. If DDH is diagnosed and treated early, however, the associated long-term morbidity can be avoided. As a result, clinicians routinely follow patients previously treated for DDH with longitudinal imaging studies to assess for dysplasia, often through skeletal maturity. Infants with a history of breech presentation are also followed closely with longitudinal imaging studies, as these infants have a higher incidence of DDH than the general population. Breech infants have a 27% incidence of DDH on newborn screening ultrasounds, and 29% are diagnosed with DDH during their 4- to 6-month follow-up, despite normal early ultrasounds [8].

The standard imaging protocol for following patients with a history of DDH or breech presentation includes ultrasonography during early infancy and anteroposterior

(AP) pelvis X-rays starting at 6 months of age. While the utility of repeat DDH evaluations at 6 months of age has been well supported, the routine use of ultrasound versus X-ray has not been studied adequately [9]. Currently, plain radiography is the standard imaging modality used to assess for DDH in 6-month-olds. However, parents are often concerned about exposing infants to ionizing radiation, despite the relatively low doses involved in plain radiography.

Ultrasound uses sound waves, not radiation, and is the imaging modality of choice for DDH in early infancy because it allows visualization of the cartilaginous femoral head [9, 15]. Nevertheless, ultrasound is not routinely used for the 6-month DDH evaluation because of potential technical concerns over cooperation from older infants and over the developing ossific nucleus obscuring ultrasound echoes [2, 10, 16]. We hypothesized that the size of the ossific nucleus in 6-month-old children would still permit effective DDH evaluations via ultrasound.

The aim of this study was to assess whether anatomic structures such as the femoral head, acetabulum, and labrum could be visualized on ultrasound and whether standard parameters used to quantify dysplasia, such as percentage of femoral head coverage, acetabular index (AI), and alpha angle, could be measured on ultrasound in order to confirm that ultrasound is a feasible alternative to plain radiography for DDH evaluations in 6-month-old children. We sought to confirm that ultrasound is a technically feasible and reliable alternative imaging modality to X-ray for evaluating DDH in 6-month-old infants.

Patients and Methods

Following institutional review board approval and power analysis, 40 consecutive patients between September 2009 and February 2011 were enrolled prospectively. We included 5- to 7-month-old infants indicated for an AP pelvis X-ray to assess for DDH. Children previously treated for DDH and those born breech were included in our series and enrolled prior to their 5- to 7-month follow-up. Children with neuromuscular disorders and neural tube defects were excluded. Additionally, 10 newborn controls were enrolled prospectively and the mean duration of hip ultrasound time was recorded to assess if patient cooperation was comparable between 6-month-olds and newborns. Patients were identified by the pediatric orthopedic surgeons at our institution, and their parents consented to participation.

Ultrasound was performed using the standard lateral, coronal approach by experienced technicians using a Philips iU22 unit (Philips Healthcare, Bothell, WA, USA) with use of a linear 12–5-MHz transducer. All images were read by three senior pediatric orthopedic surgeons (DG, RW, SD) who were unfamiliar with the patient histories for standard measures of hip dysplasia, including AI, alpha angle, and percent coverage of the femoral head. On X-ray, measurements for the AI were performed in the standard fashion by drawing a line through the lateral outer edge of the acetabulum to the triradiate cartilage and measuring the angle between that line and Hilgenreiner's line. An AI of 30° or greater was considered evidence of dysplasia [12]. The position of the femoral head in the quadrants formed by Hilgenreiner's and Perkin's lines was also determined to evaluate for dysplasia. In addition, the presence or absence of the ossific nucleus was recorded.

The ultrasound images were de-identified and read separately from the X-rays to ensure that the readers were blinded both to patient information and to the corresponding X-ray findings. The best coronal mid-acetabular image, with the iliac bone seen as a straight line parallel to the edge of the image, was chosen for each hip for analysis. As standard protocol at the hospital, the ischium was visualized as a semi-circle at the inferior aspect of the image to confirm a good picture. Using the same pre-selected coronal view, the three blinded reviewers measured the alpha angle, with less than 60° considered evidence of dysplasia [4]. We also measured the bony rim percent coverage of the femoral head, with less than 50% coverage considered evidence of dysplasia (Fig. 1). After the 6-month exam, patients were followed with AP pelvis X-rays for the remainder of their evaluations as needed. Treatment decisions were based on X-ray, which was the hospital standard of care. The mean follow-up period for this study was 26 months after the date of the 5- to 7-month-old evaluation.

A statistician calculated the inter-observer reliability for the AI, the alpha angle, and the percent coverage of the femoral head measurements by calculating the intraclass correlation coefficients (ICC). To determine how measures of hip dysplasia on X-ray corresponded with measures of hip dysplasia on ultrasound, the Pearson correlation coefficients

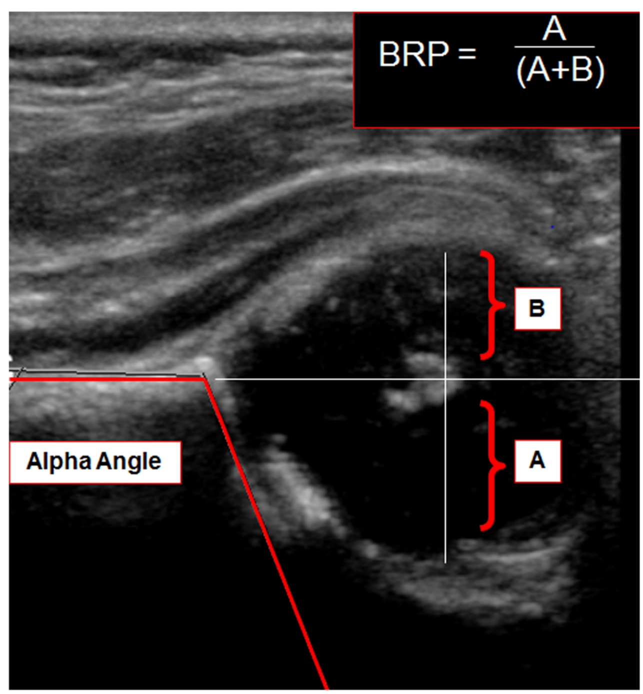

Fig. 1. Bony rim percent (BRP) coverage of the femoral head was measured on the coronal ultrasounds by dividing the measurement for the portion of the femoral head that was covered by the acetabulum (a) by the total diameter of the femoral head (a+b).

were calculated for the key variables: AI versus alpha angle and AI versus percent coverage of the femoral head. Finally, the average time required to perform the ultrasounds in 5- to 7-month-old infants was compared to the average time required to perform hip ultrasounds in the randomly selected population of 10 newborns.

Results

On 31 of the 40 enrolled patients, we obtained AP pelvis X-rays and bilateral, non-stress hip ultrasounds. One patient was lost to follow up, and the parents of eight patients withdrew consent, refusing X-rays after their children's ultrasounds were completed. A total of 62 hips were available for analysis, with a mean follow-up time of 26 months after the 5- to 7-month imaging exam date. Ninety-two percent of the children had a history of ultrasound-documented DDH in early infancy, while 8% of the children met inclusion criteria secondary to breech presentation.

Clear images were obtained in all patients, despite the presence of the ossific nucleus in 41 of 62 hips (66%) (Fig. 2). There was no difference in the mean time required to perform the ultrasounds in our study population versus newborns. The mean time to complete the ultrasounds in the 5- to 7-month-olds was 5.2 min (range, 1–19; mode 2). The mean time to complete the newborn examinations was 4.9 min (range, 3–7; mode 5).

Only one of the 62 hips was diagnosed with a late dislocation at the time of the 5- to 7-month screening examination, and all three blinded readers correctly diagnosed the dislocation via both X-ray (Fig. 3a) and ultrasound (Fig. 3b).

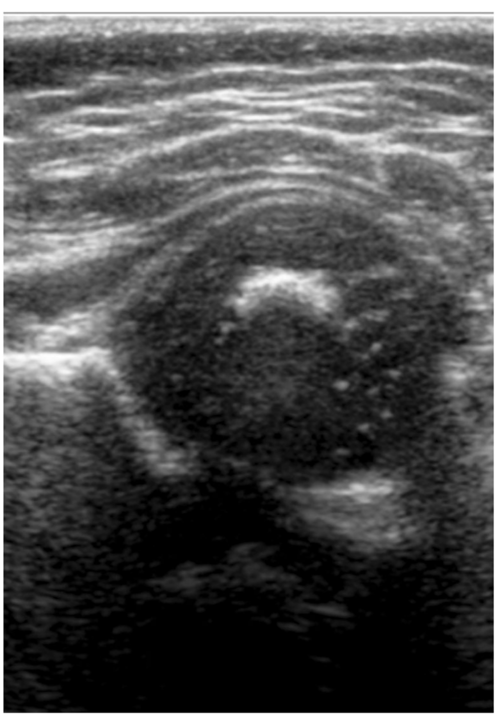

Fig. 2. Good quality ultrasound images were obtained in all patients, despite the presence of the ossific nucleus in 66% of all hips.

The patient underwent closed reduction, arthrogram, and spica casting. Only one of the three readers diagnosed mild subluxation on X-ray in two hips based on slight lateralization of the ossific nucleus in the quadrants formed by Hilgenreiner's and Perkin's lines (Fig. 4). The other two readers did not diagnose those two hips as subluxated on X-ray. However, both of those hips were deemed abnormal on ultrasound based on a bony rim percent coverage of less than 50%. The treating provider did not institute treatment for under-coverage at the 5- to 7-month visit, based on their evaluation at the time, that the X-ray was normal. At 1 year of age, the acetabular indices had normalized (less than 21) [14], and neither patient was treated for residual dysplasia during the study period.

Of the remaining 59 hips that were read as located by all three readers on all imaging modalities, X-ray identified four more abnormalities based on AI greater than or equal to 30°. All four hips were corroborated as abnormal on ultrasound. Ultrasound identified 13 total abnormalities in these 59 hips: 10 alpha angles less than 60° and 13 with percent coverage of the femoral head of less than 50%. There were no false negatives on ultrasound. Follow-up X-rays for these patients remained normal, and no treatment was initiated for these patients.

The average AI in the study population was 24.8°, and the average alpha angle was 63°. The average percent coverage of the femoral head was 55%. Elevated AI on X-ray was negatively correlated with decreased percent coverage of the femoral head on ultrasound, with a Pearson correlation coefficient of − 0.4 ($p = 0.003$) (Fig. 5). However, AI on X-ray was not correlated with alpha angle on ultrasound (Fig. 6). Finally, the inter-observer reliability for alpha angle was relatively low ICC (0.4), while the other outcome measures were higher (AI ICC 0.8, percent coverage ICC 0.7).

Discussion

We conducted this study to confirm that ultrasound was a feasible alternative to X-ray for the 6-month DDH evaluation. There were no significant differences in time for ultrasound at 6 months compared to ultrasound of newborns, indicating patient cooperation was not a problem. Elevated AI on X-ray was significantly associated with lower percent coverage of the femoral head and lower percent coverage of the femoral head on ultrasound, while no association was found between X-ray AI and ultrasound alpha angle. No false negatives were reported for ultrasound.

There were several limitations to our study. We imaged only 62 high-risk hips, and we had no children without a diagnosis or risk factors for DDH in our study population. We also diagnosed only one late dislocation in 5- to 7-month-olds during our study period. In addition, patients were not followed through skeletal maturity, as our mean follow-up time was 26 months. The inter-observer reliability rate was low for alpha angle measurements; while this is consistent with the literature, variance in alpha angle measurements may contribute to the insignificant

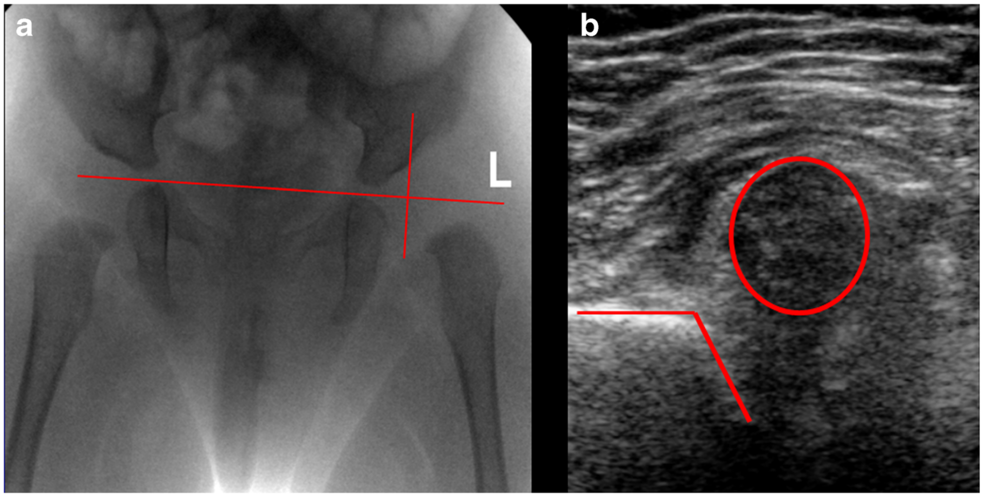

Fig. 3. The one late dislocation was diagnosed correctly by all three blinded readers via X-ray and ultrasound. **a** X-ray demonstrating a left hip dislocation. Hilgenreiner's and Perkin's lines are drawn on the right side of the figure to help demonstrate the left hip dislocation. **b** Coronal ultrasound image demonstrating the dislocated femoral head with zero bony rim percent coverage. The femoral head and acetabulum are outlined on the right side of the figure for clarity.

relationship between alpha angle and AI. Despite these limitations, we demonstrated that ultrasound is a technically feasible DDH imaging modality in 6-month-old infants, despite the developing ossific nucleus. Ultrasound and X-ray were both capable of detecting the one late dislocation, and ultrasound had no false negatives.

Despite the age of our study patients and the appearance of the ossific nucleus in 66% of the hips, ultrasound provided good quality images with 100% diagnostic correlation to X-ray in all patients. The experience of our ultrasound technicians in our high-volume, tertiary care institution likely contributed to the high quality of the images. Despite concerns over performing ultrasounds in more mobile and potentially less-cooperative older infants, there was no difference between the mean time required to obtain good quality images in our study population and newborns.

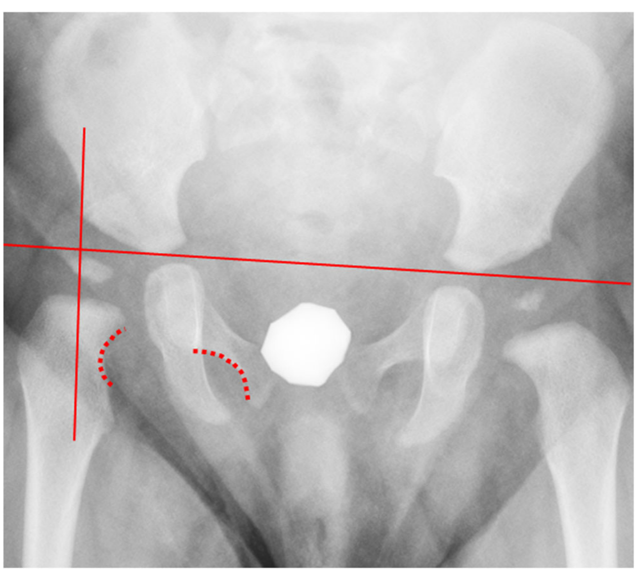

Fig. 4. Two hips were diagnosed as mildly subluxated by only one of three readers on X-ray. The diagnosis was made based on slight lateralization of the ossific nucleus, as seen in the right hip in this figure.

There was only one late persisting hip dislocation in this study population, and the dislocation was diagnosed correctly by all three readers via both X-ray and ultrasound. Importantly, ultrasound had no false negatives; no patients with normal 6-month ultrasounds had abnormal subsequent X-rays or required treatment during our mean follow-up period of 26 months. Two hips were read as mildly subluxated by only one of the three readers on X-ray, based on slight lateralization of the ossific nucleus. Both hips were deemed abnormal on ultrasound based on percent coverage of the femoral head less than 50%. The slight lateralization of the ossific nucleus on X-ray was likely due to rotation in both cases, and both hips had normal subsequent X-rays at 12 months of age. Ultrasound was perhaps overly sensitive when compared to X-ray because ultrasound identified 13 slight abnormalities among the 59 located hips, none of which required treatment during the 26-month follow-up period. Four of these hips were also diagnosed as abnormal on X-ray. The abnormal ultrasound and X-ray values for these 13 hips were all mild; none had concerning alpha angles of less than 50° [4] or AIs greater than 32°.

AI, the key measure of acetabular dysplasia on X-ray, was not significantly correlated with alpha angle; however, this result was impacted potentially by a low alpha angle ICC. ICC measurements of inter-observer reliability are consistently lower for alpha angle than for other measures of hip dysplasia, and our values are consistent with those reported in the literature [6, 10].

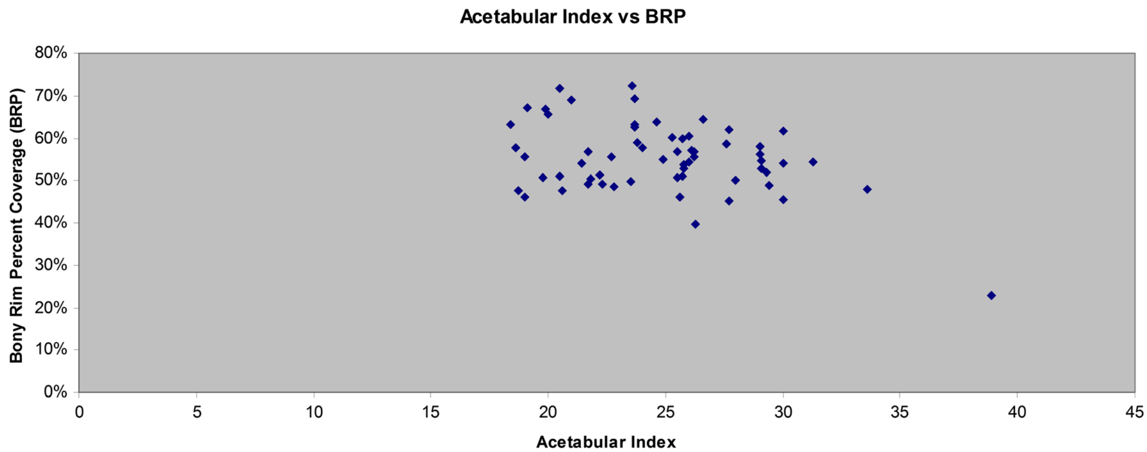

Fig. 5. Acetabular index on X-ray was negatively correlated with percent coverage of the femoral head on ultrasound, with a Pearson correlation coefficient of − 0.4 ($p = 0.003$). Best exemplified by the one dislocated hip, higher values for acetabular index were correlated with lower values for percent coverage of the femoral head.

While previous studies have concluded that radiographs are more reliable than ultrasound after 4 to 6 months of age due to the appearance of the ossification center of the femoral head [1], this study demonstrates that ultrasound is effective up to 7 months of age, even if the ossification center is present. Additionally, this study confirms results of a previous retrospective study that found radiographic follow-up for DDH can be delayed until 2 years of age [3]. Long-term follow-up is essential in patients with hip dysplasia to avoid late acetabular dysplasia, despite concerns of radiation from frequent radiographs [11, 13]. One study calculated the risk of exposure inducing death from radiographs at 6 and 12 months of age to be less than one per million, although the risk did double between the 6- and 13-month radiographs [11]. This study provides further evidence that ultrasound, even in older infants, can be used to assess hip dysplasia.

Based on these findings, it is feasible to use ultrasound for evaluating DDH in 6-month-old infants. All relevant anatomical structures can be visualized and all parameters used to diagnose DDH can be measured. X-rays are still obtained for the remainder of the longitudinal imaging exams through skeletal maturity starting at 1 year of age, when the ossification of the femoral head precludes adequate visualization of the medial acetabulum [15]. This study did not have enough abnormal hips due to patient attrition to determine the sensitivity and specificity of ultrasound for diagnosing hip dysplasia in 6-month-olds. However, ultrasound corroborated all abnormalities diagnosed on X-ray and identified additional subtle abnormalities, which were not clinically significant. For this reason, we obtained X-rays in all 6-month-olds with abnormal ultrasounds to confirm the presence of residual dysplasia. To confirm the findings of our study and to determine the sensitivity and specificity of ultrasound at diagnosing dysplasia in 6-month-olds, we recommend a larger, multi-center, prospective study that includes normal, high-risk, and abnormal hips.

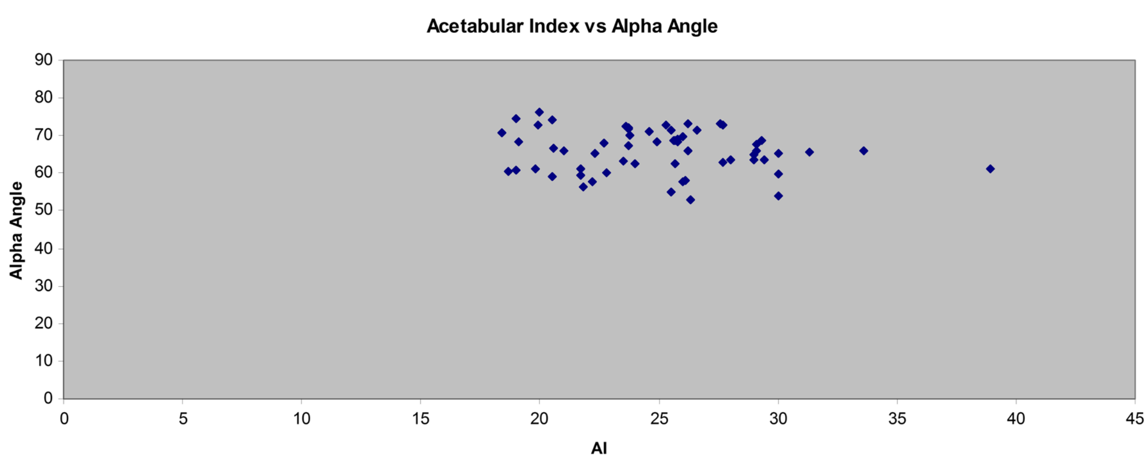

Fig. 6. Acetabular index (AI) was not correlated with alpha angle.

Acknowledgements The authors wish to thank Dr. John Blanco and Dr. David Scher for contributing their patients to this study.

Funding Huong Do, MA, declares that research reported in this publication was financially supported by the National Center for Advancing Translational Sciences of the National Institute of Health (no. UL1-RR024996).

Compliance with Ethical Standards

Conflict of Interest: Alison Kitay, MD, Roger F. Widmann, MD, Shevaun M. Doyle, MD, Huong T. Do, MA, and Daniel W. Green, MD, declare that they have no conflicts of interest.

Human/Animal Rights: 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 1975, as revised in 2013.

Informed Consent: Informed consent was obtained from parents of patients included in this study.

Required Author Forms: Disclosure forms provided by the authors are available with the online version of this article.

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