Comparison of Ultrasound and MRI for the Diagnosis of Glenohumeral Dysplasia in Brachial Plexus Birth Palsy

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Background: In this study, we investigated the agreement between measurements made on ultrasound and those made on magnetic resonance imaging (MRI) in the assessment of glenohumeral dysplasia resulting from brachial plexus birth palsy.

Methods: Thirty-nine patients (14 male and 25 female) with brachial plexus birth palsy were evaluated at 2 tertiary care centers. All patients underwent ultrasonography and MRI for suspected glenohumeral dysplasia. Studies were obtained at an average of 2 months apart (range, 0 to 6 months). The average patient age at the time of the initial imaging study was 20 months (range, 4 to 54 months). Four blinded independent evaluators measured the alpha angle, the posterior humeral head displacement (PHHD), and glenoid version on both the ultrasound and MRI study for each patient. The percentage of the humeral head anterior to the scapular axis (PHHA) was determined on MRI only. Measurements were obtained on OsiriX software (Pixmeo). Intraclass correlation coefficients (ICCs) were used to assess the intrarater and interrater reliability, and Bland-Altman plots were used to compare MRI and ultrasound measurement agreement.

Results: We found excellent interrater reliability for measurements of the alpha angle on MRI, glenoid version on MRI, and the alpha angle on ultrasound (ICC: 0.83, 0.75, and 0.78, respectively). The interrater reliability for the PHHD on both MRI and ultrasound was good (ICC: 0.70 and 0.68, respectively), and the interrater reliability for the PHHA on MRI was fair (ICC: 0.57). However, the interrater reliability for glenoid version on ultrasound was poor (ICC: 0.30). Relative to MRI measurements, ultrasound measurements were found to underestimate the alpha angle and glenoid version by an average of 13° ± 23° and 6° ± 17°, respectively, and overestimate the PHHD by an average of 4% ± 20%. Increasing patient age corresponded with a significant increase in the MRI-ultrasound measurement difference for the alpha angle ($p < 0.01$) and a marginally significant increase in the difference for the PHHD ($p < 0.06$).

Conclusions: Measurements on MRI and ultrasound were reliable, with measured bias. The poor agreement between measurements on MRI and ultrasound calls into question the validity of using ultrasonography as a stand-alone modality in the evaluation of glenohumeral dysplasia. MRI remains the gold standard for fully evaluating the glenohumeral joint. The clinical role of ultrasonography may be that of a screening tool or a way of evaluating joint reduction in real time.

Level of Evidence: Diagnostic Level I. See Instructions for Authors for a complete description of levels of evidence.

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The association between brachial plexus birth palsy and glenohumeral dysplasia was recognized over a century ago[1]. Persistent upper trunk palsy (C5-C6) creates uneven muscular development and contractility around the growing shoulder, where weak and shortened external rotators are relatively overpowered by intact internal rotators. The resulting

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orientation of the humeral head produces increased force across the posterior aspect of the glenoid. Dysplasia progresses in a characteristic pattern reflective of slowed physeal growth and articular changes in this location. This pattern has been classified with use of magnetic resonance imaging (MRI), arthrography, and arthroscopy by various authors[2-4]. Increasing glenoid retroversion, posterior glenoid deformation, and humeral head subluxation are consistent features of these classifications. Surgical treatment to rebalance the shoulder with tendon release and/or transfer has shown promise in reversing these changes[5]. Early diagnosis and accurate assessment of dysplasia before and after treatment are critical.

Internal rotation contracture is often the first clinical sign of dysplasia. Lack of external rotation beyond neutral in a patient with brachial plexus birth palsy is virtually diagnostic of glenohumeral dysplasia[6,7]. This examination finding warrants further evaluation with imaging. Historically, radiography and computed tomography (CT) were used to assess joint congruity[8,9]. However, these techniques were limited by poor resolution of the unossified glenoid and concerns about exposure to ionizing radiation. Cartilage-sensitive imaging modalities such as MRI and ultrasonography are currently the preferred methods for evaluating glenohumeral dysplasia. MRI provides superior resolution but requires sedation or general anesthesia in children. This imparts additional cost and risk. In contrast, ultrasound imaging provides less fine detail but may be performed at the bedside and allows dynamic evaluation of the joint.

Different measurement techniques have been developed to assess glenohumeral dysplasia with each imaging modality. Measurements on MRI are considered the gold standard and are similar to measurements previously made using CT. These include glenoid version and the percentage of the humeral head anterior to the scapular axis (PHHA)[4,10]. Measurements on ultrasound were originally described for a subset of patients with dysplasia who had infantile dislocation[11,12]. These include the alpha angle and the posterior humeral head displacement (PHHD) relative to the posterior scapular margin[12]. Although measurements obtained with each imaging technique have been shown to have good intraobserver and interobserver reliability, their relationship and relative validity remain unclear. MRI findings including glenoid retroversion, glenoid biconcavity, humeral head flattening, and humeral head subluxation have been shown to correlate with surgical findings[3,4]. To our knowledge, ultrasonography has only been evaluated for detecting humeral head subluxation[13]. In progressive dysplasia, increasing humeral head subluxation may occur concurrently with increasing deformity at the posterolateral aspect of the glenoid. This is problematic because ultrasound measurements reference the posterolateral aspect of the glenoid to define humeral head position. The primary goal of the present study was to investigate the agreement between measurements on MRI and ultrasound in the assessment of glenohumeral dysplasia. Secondary goals were to explore the effect of patient age on measurement agreement and to determine the effectiveness of ultrasonography as a screening tool for MRI-confirmed dislocation.

Materials and Methods

Thirty-nine consecutive patients (14 male and 25 female) with glenohumeral dysplasia were prospectively evaluated between June 2009 and March 2014, at 2 tertiary care centers. All patients had been diagnosed with upper (C5-C6) or extended upper (C5-C7) plexus palsy. Patients included in the study had persistent palsy beyond 3 months of age and clinical signs of glenohumeral dysplasia, such as internal rotation contracture, posterior humeral head prominence, apparent shortening of the arm, and axillary-fold asymmetry. The affected shoulder was evaluated with use of both MRI and ultrasonography. Studies were obtained at an average of 2 months apart (range, 0 to 6 months). The order of the imaging studies varied: ultrasound was performed as the initial diagnostic study for 18 patients without previous imaging and as a follow-up study for 21 patients with prior MRI. The average patient age at the time of the initial imaging study was 20 months (range, 4 to 54 months). Exclusion criteria were an age of >5 years, global plexus involvement, previous surgery or surgery between imaging studies, studies performed >6 months apart, and weak midline function (an internal rotation score of <4 on the modified Mallet scale[14]). The institutional review boards of both centers approved all aspects of the study.

Ultrasonography was performed by 2 senior authors (D.A.Z. and K.J.L.). Both are pediatric upper-extremity surgeons with between 5 and 6 years of experience using ultrasound to assess glenohumeral dysplasia. The studies were performed in conjunction with a musculoskeletal radiologist or independently once the surgeon had completed a training course in musculoskeletal sonography. All studies were performed in clinic using a linear 12-MHz transducer on the LOGIQ e platform (GE Healthcare). Sonography was performed from a posterior approach, as described by Hunter et al.[11]. The arm was positioned by the side and the shoulder was placed in neutral rotation. The surgeon performing the study was instructed to select a single axial image for each patient that best showed the posterior aspect of the scapula, the glenoid, and the humerus. Images were then deidentified and saved as JPEG (Joint Photographic Experts Group) files. MRI evaluation was performed using a 1.5-T scanner with conscious sedation of the patient and monitoring. The patient was placed supine with the affected arm and shoulder in the same position as for ultrasound. The standard sequence protocol included axial T2 and 3-dimensional (3-D) gradient-echo (2.5-mm section thickness with 0 spacing) images along with fat-saturated fast-spin-echo T1, proton density, and T2-weighted images (3-mm section thickness with 0 spacing). The deidentified MRI was saved as a DICOM (Digital Imaging and Communications in Medicine) file. Evaluators were provided with the preselected ultrasound image and entire MRI study for each patient.

Measurements were obtained on OsiriX software (Pixmeo) by 4 blinded independent evaluators: 2 pediatric upper-extremity surgeons, 1 orthopaedic hand fellow, and 1 orthopaedic resident. The deidentified studies were distributed to the evaluators in random order. Evaluators were asked to measure the alpha angle, the PHHD, and glenoid version on both MRI and ultrasound. In addition, evaluators were asked to measure the PHHA on MRI alone (Figs. 1 and 2). Measurements were performed once for all 39 patients and twice, 1 week apart, for a subgroup of 10 patients. The 2 senior authors were also asked to categorize the glenohumeral joint on each MRI and ultrasound as either "dysplastic" or "dislocated" on the basis of overall appearance.

Evaluators were given written instructions on how to perform each measurement as well as a sample MRI and ultrasound image with predrawn measurements. The group was allowed to practice reproducing each measurement on nonstudy images prior to data collection. All measurements were performed with digital angle and distance tools using only osseous landmarks. Each evaluator independently selected all landmarks. Evaluators were instructed to perform all MRI measurements on the single axial slice just inferior to the coracoid and the spinoglenoid notch. The measurement technique used for each parameter was identical on MRI and ultrasound and is described in the Appendix.

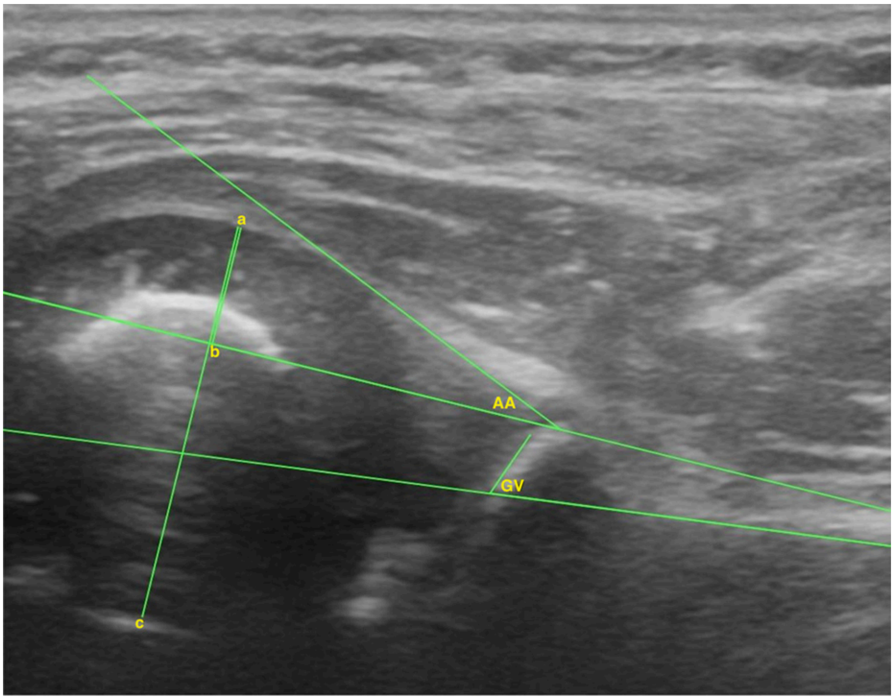

Fig. 1

Axial ultrasound image of a 7-month-old patient with glenohumeral dysplasia (12-MHz transducer, GE LOGIQ e platform). Measurements of the alpha angle (AA), glenoid version (GV − 90°), and the posterior humeral head displacement (PHHD) (ab/ac × 100%) are shown.

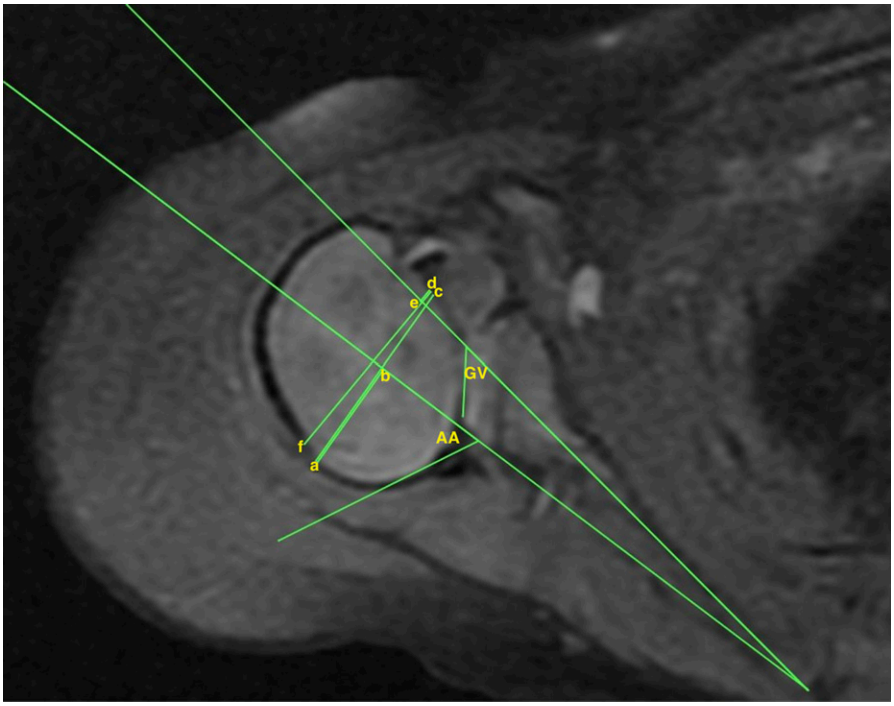

Fig. 2

Proton-density-weighted, fat-suppressed axial MRI of the same patient as in **Fig. 1** at 10 months of age. Measurements of the alpha angle (AA), glenoid version (GV − 90°), the posterior humeral head displacement (PHHD) (ab/ac × 100%), and the percentage of the humeral head anterior to the scapular axis (PHHA) (de/df × 100%) are shown.

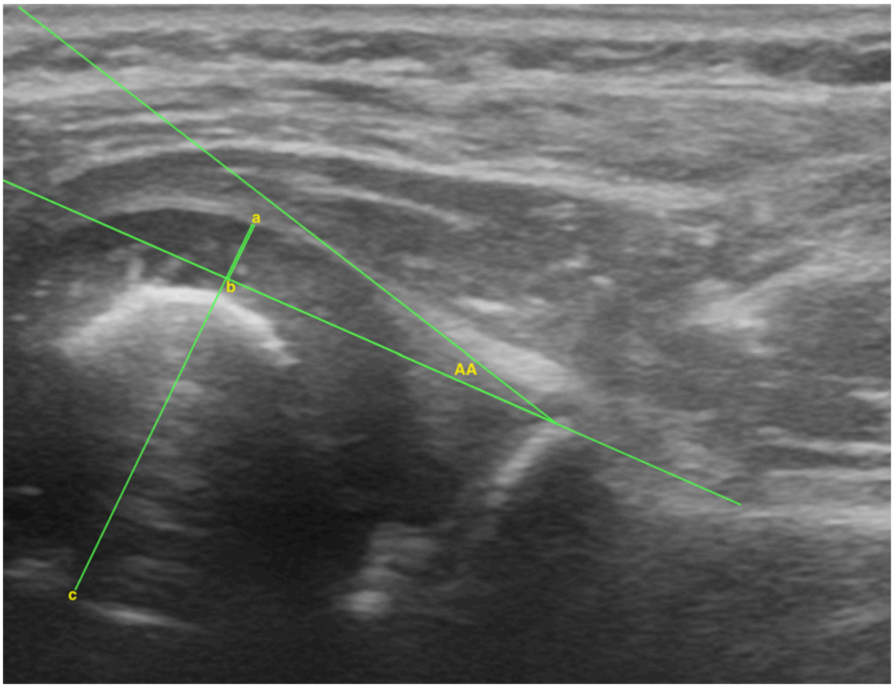

Fig. 3
Modified measurement technique on ultrasound. The posterior border of the scapula is defined along the metaphyseal flare of the posterior aspect of the glenoid. Measurements of the alpha angle (AA) and the posterior humeral head displacement (PHHD) (ab/ac × 100%) are shown.

Statistical Methods

Intrarater and interrater reliability were assessed using the intraclass correlation coefficient (ICC) with the 95% confidence interval (CI). The ICC was calculated for each MRI and ultrasound measurement. Measurement parameters included the alpha angle, glenoid version, the PHHD, and the PHHA. Intrarater reliability was calculated for the group of 4 evaluators, and interrater

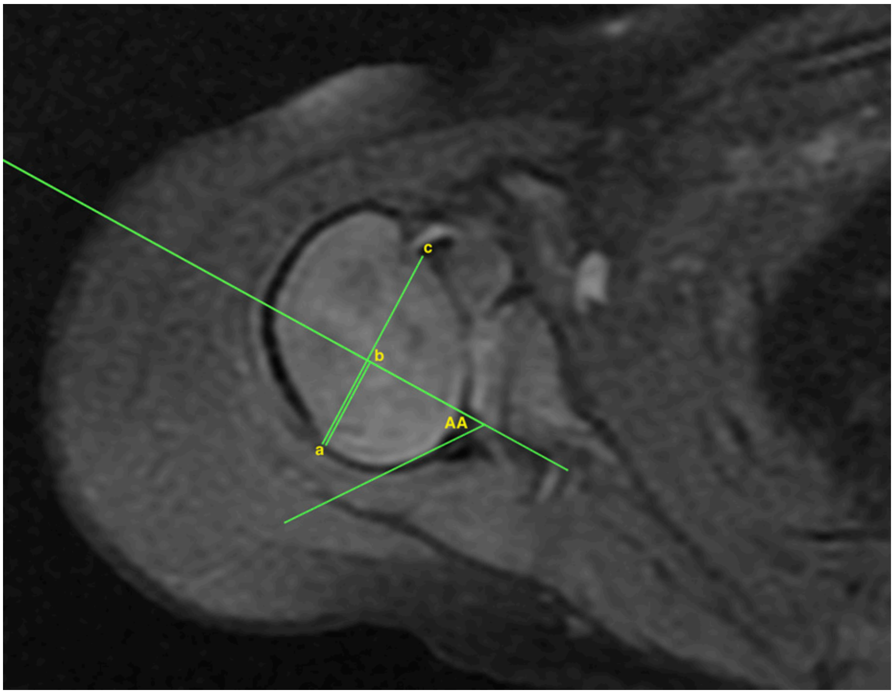

Fig. 4
Modified measurement technique on MRI. The posterior border of the scapula is defined along the metaphyseal flare of the posterior aspect of the glenoid. Measurements of the alpha angle (AA) and the posterior humeral head displacement (PHHD) (ab/ac × 100%) are shown.

TABLE I Intrarater Reliability

	4 Evaluators*	1 Evaluator*
Alpha angle		
MRI	0.62 (0.32-0.87)	0.65 (0.08-0.90)
Ultrasound	0.91 (0.78-0.97)	0.82 (0.43-0.95)
Glenoid version		
MRI	0.89 (0.74-0.96)	0.80 (0.37-0.95)
Ultrasound	0.75 (0.50-0.92)	0.73 (0.22-0.93)
PHHD		
MRI	0.82 (0.61-0.94)	0.83 (0.44-0.95)
Ultrasound	0.87 (0.71-0.96)	0.85 (0.52-0.96)
PHHA		
MRI	0.84 (0.65-0.95)	0.69 (0.16-0.91)

*The values are given as the ICC, with the 95% CI in parentheses. 1 evaluator = the senior author (D.A.Z.) who used a modified measurement technique.

reliability was calculated for the group of 3 evaluators who used an identical measurement technique. One of the senior authors (D.A.Z.) used a modified measurement technique, with those measurements analyzed separately. His technique defined the posterior border of the scapula along the metaphyseal flare of the posterior aspect of the glenoid rather than the scapular body (Figs. 3 and 4). It was thought that this might increase measurement consistency between MRI and ultrasound. ICCs were calculated using the Shrout and Fleiss method[15,16]. An ICC of ≥0.75 was considered excellent, ≥0.60 to <0.75 was good; ≥0.40 to <0.60 was fair, and <0.40 was poor[16].

Bland-Altman analysis was used to analyze the difference between measurements made on MRI and ultrasound[17]. With this analysis, the difference between each examiner's MRI and ultrasound measurements (y axis) was plotted relative to the severity of dysplasia (x axis). The mean measurement difference across the spectrum of dysplasia indicates whether dysplasia is overestimated or underestimated by one imaging modality. The standard deviation (SD) indicates the extent of the difference between MRI and ultrasound measurements. Scatterplots show systematic bias.

Using Bland-Altman analysis, we compared each MRI and ultrasound measurement of the alpha angle, glenoid version, and the PHHD made by the group of 4 examiners for the cohort of 39 patients. Separate subgroup analyses included patients ≤1 year of age (n = 11) and patients >1 of age (n = 28); patients who had both studies performed within 1 month (n = 14); and data recorded by the senior author who used a different measurement technique. The effect of age on MRI-ultrasound agreement was further evaluated with the use of linear regression analyses for each measurement parameter. Categorical data were analyzed to determine the sensitivity and specificity of ultrasound as a predictor of dislocation as confirmed on MRI.

Results

The intrarater reliability was calculated for a subgroup of 10 patients (3 male and 7 female) from the original cohort of 39 patients; the average age was 18 months (range, 6 to 25 months). We found good intrarater reliability for the alpha angle on MRI (ICC: 0.62), and excellent intrarater reliability for the alpha angle on ultrasound (ICC: 0.91), glenoid version on MRI (ICC: 0.89), glenoid version on ultrasound (ICC: 0.75), the PHHD on MRI (ICC: 0.82), the PHHD on ultrasound (ICC: 0.87), and the PHHA on MRI (0.84). The intrarater reliability for the senior author using a different measurement technique did not differ significantly from that of the group (Table I).

The interrater reliability was calculated for the 39 patients (14 male and 25 female) meeting our inclusion criteria; the average age was 20 months (range, 4 to 54 months). We found excellent interrater reliability for the alpha angle on MRI (ICC: 0.83), the alpha angle on ultrasound (0.78), and glenoid version on MRI (ICC: 0.75). The interrater reliability was good for the PHHD on MRI (ICC: 0.70) and on ultrasound (ICC: 0.68), and fair for the PHHA on MRI (ICC: 0.57). The interrater reliability for glenoid version on ultrasound was poor (ICC: 0.30) (Table II). Relative to measurements made on MRI, measurements made on ultrasound were found to underestimate

TABLE II Interrater Reliability Among 3 Evaluators by Study Time Interval*

	Study Time Interval		
	0-1 Mo., N = 14	0-3 Mo., N = 34	0-6 Mo., N = 39
Alpha angle			
MRI	0.80 (0.60-0.93)†	0.80 (0.69-0.89)†	0.83 (0.73-0.90)†
Ultrasound	0.76 (0.52-0.91)†	0.78 (0.64-0.87)†	0.78 (0.66-0.87)†
Glenoid version			
MRI	0.57 (0.26-0.81)	0.71 (0.55-0.83)†	0.75 (0.61-0.85)†
Ultrasound	0.31 (0.02-0.65)	0.32 (0.32-0.57)	0.30 (0.02-0.56)
PHHD			
MRI	0.65 (0.23-0.87)†	0.72 (0.43-0.86)†	0.70 (0.43-0.84)†
Ultrasound	0.62 (0.32-0.84)†	0.69 (0.53-0.82)†	0.68 (0.53-0.80)†
PHHA			
MRI	0.53 (0.22-0.79)	0.53 (0.32-0.71)	0.57 (0.35-0.73)

*The values are given as the ICC, with the 95% CI in parentheses. †Good to excellent interrater reliability (ICC of ≥0.60).

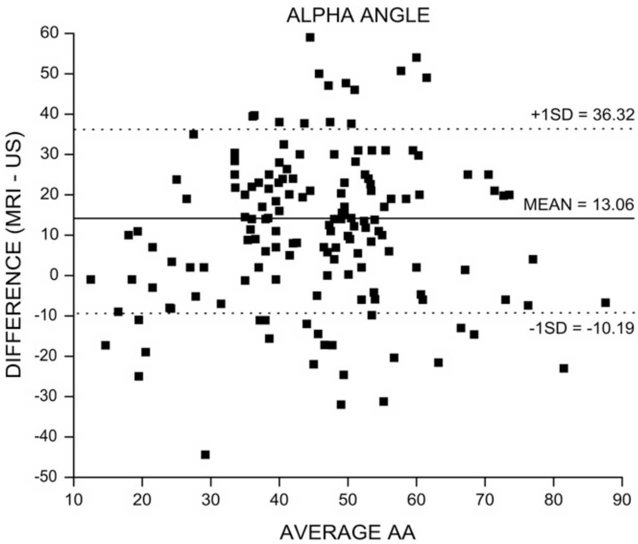

Fig. 5A

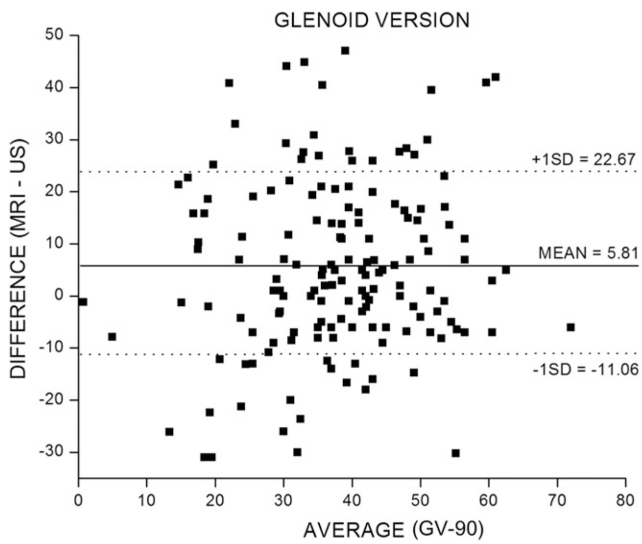

Fig. 5B

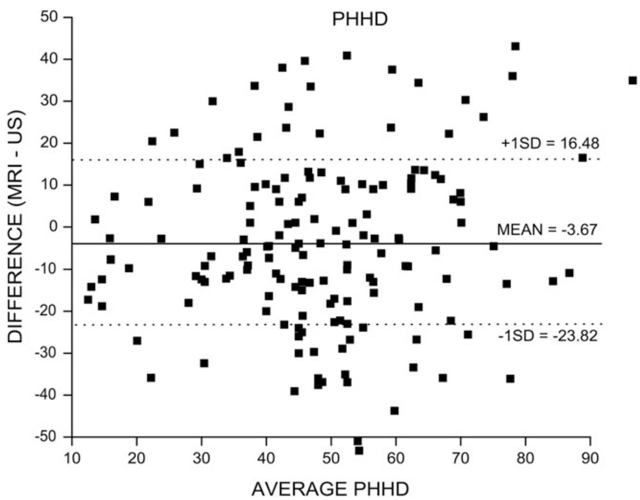

Fig. 5C

Figs. 5-A, 5-B, and 5-C Bland-Altman analyses of MRI-ultrasound (US) agreement for the alpha angle (AA) (**Fig. 5-A**); glenoid version (GV − 90) (**Fig. 5-B**); and the posterior humeral head displacement (PHHD) (**Fig. 5-C**). Each point represents the difference between MRI and ultrasound measurements for a single patient (y axis) relative to the average value of these measurements (x axis). There were a total of 156 points in each analysis (39 patients × 4 evaluators).

the alpha angle and glenoid version and overestimate the PHHD by an average (and SD) of 13° ± 23°, 6° ± 17°, and 4% ± 20%, respectively (Figs. 5-A, 5-B, and 5-C). The SDs were large for all parameters measured, indicating poor agreement between MRI and ultrasound. Scatterplots did not show any improvement in agreement between measurements

TABLE III MRI-Ultrasound Measurement Difference*

	Study Time Interval		
Parameter	0-1 Mo., N = 14	0-3 Mo., N = 34	0-6 Mo., N = 39
Alpha angle *(deg)*	9 ± 18	11 ± 20	13 ± 23
Glenoid version *(deg)*	7 ± 16	6 ± 17	6 ± 17
PHHD *(%)*	−5 ± 19	−4 ± 20	−4 ± 20

*The values are given as the mean and the standard deviation.

of less severe dysplasia. These findings persisted despite the adjustments in measurement technique by the senior author. A separate Bland-Altman analysis of his data found that measurements made on ultrasound underestimated the alpha angle and glenoid version and overestimated the PHHD by an average of 8° ± 26°, 3° ± 14°, and 5% ± 11%. Agreement between MRI and ultrasound did not significantly improve when the senior author's data were evaluated independently.

Subgroup analyses of patients for whom MRI and ultrasound studies were performed within 3 months (n = 34)

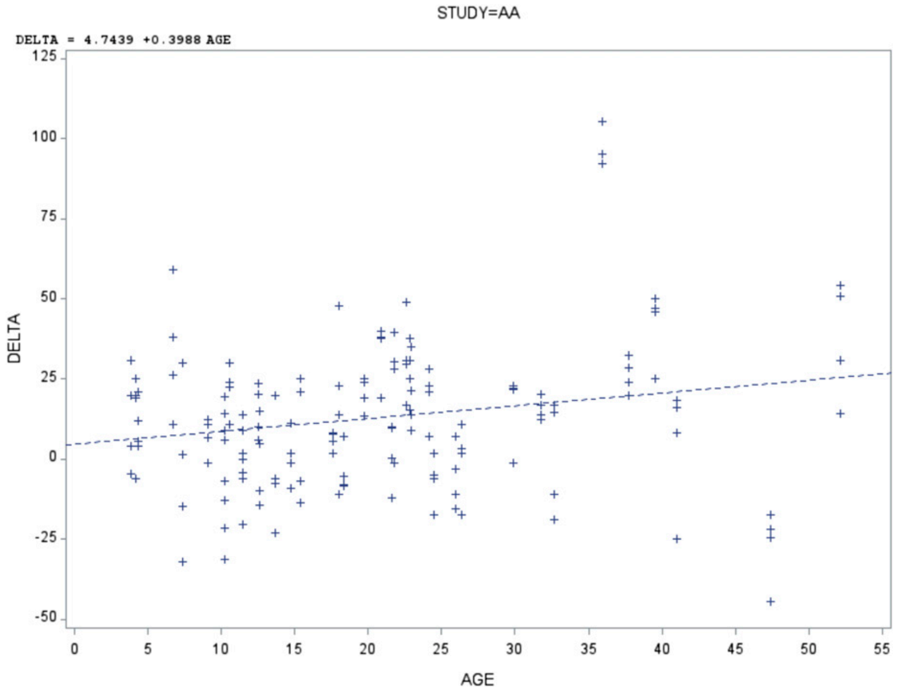

Fig. 6A

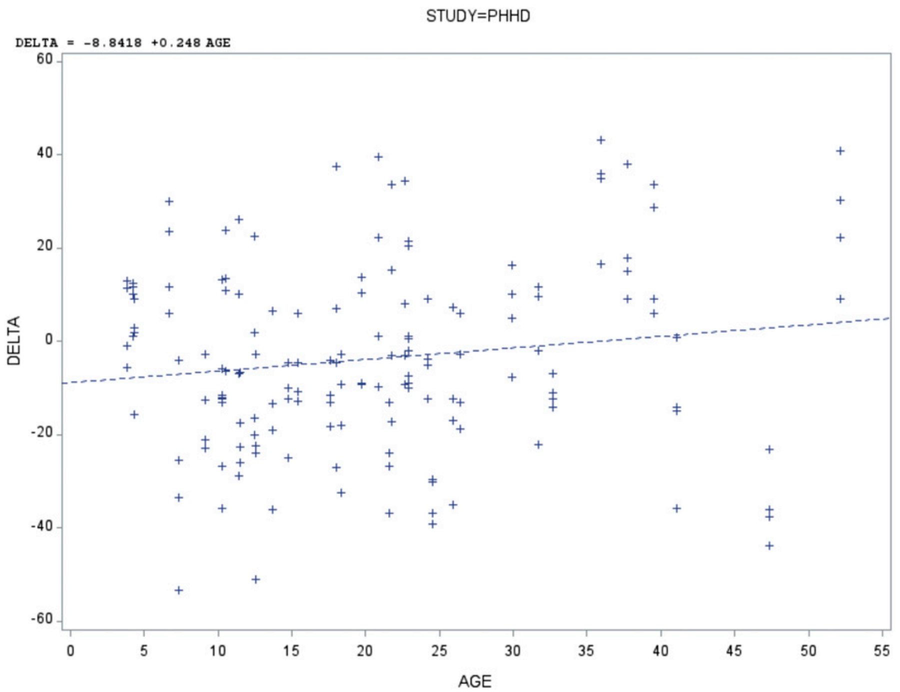

Fig. 6B

Figs. 6-A and 6-B Linear regression analyses of the measurements of the alpha angle (AA) (**Fig. 6-A**) and posterior humeral head displacement (PHHD) (**Fig. 6-B**). X axis = age in months, and y axis = MRI-ultrasound measurement difference (delta).

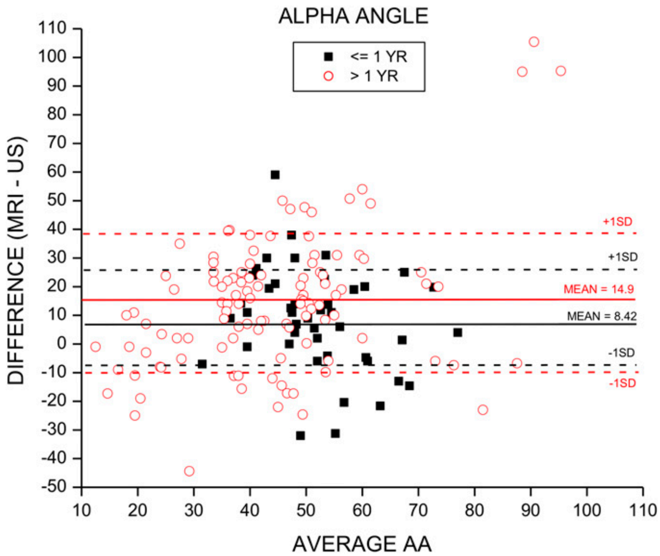

Fig. 7

Bland-Altman analysis comparing MRI-ultrasound agreement of alpha angle measurements (as measured by degrees) for patients ≤1 and >1 year of age.

or 1 month (n = 14) of each other found no improvement in the interrater reliability or in MRI-ultrasound agreement (Table II). Bland-Altman analysis again found poor agreement between MRI and ultrasound measurements (Table III).

Increasing patient age was found to increase the MRI-ultrasound measurement difference for the alpha angle and the PHHD (Figs. 6-A and 6-B). The difference between alpha angle measurements increased by 0.4° per additional month of age, which was significant ($p < 0.01$). The difference between PHHD measurements increased by 0.25% per additional month of age, which was marginally significant ($p < 0.06$). No relationship was found for glenoid version. Bland-Altman analysis found closer agreement between MRI and ultrasound measurements for the alpha angle in patients who were ≤1 year of age (an average difference of 8° ± 18°) compared patients who were >1 year of age (an average difference of 15° ± 25°) (Fig. 7). There was minimal difference in the group means for glenoid version and PHHD (delta of ≈1).

Categorical evaluations (i.e., dysplasia, dislocation) were used to assess the effectiveness of ultrasonography as a screening tool for MRI-confirmed dislocation. Ultrasound was found to have a sensitivity of 0.61 (95% CI: 0.43 to 0.76), a specificity of 0.93 (95% CI: 0.79 to 0.98), a positive predictive value of 0.89 (95% CI: 0.69 to 0.97), and a negative predictive value of 0.71 (95% CI: 0.57 to 0.83).

Discussion

Multiple studies support the use of MRI and ultrasonography for the evaluation of glenohumeral dysplasia in patients with brachial plexus birth palsy. Different patient demographics among these studies present a source of confusion. Ultrasonography was originally proposed as a screening method for posterior humeral head dislocation in neonates[7,11,12,18,19]. Measurements of the alpha angle and the PHHD on ultrasound have been shown to have good intraobserver and interobserver reliability in this population[12]. In contrast, MRI is considered the gold standard for evaluating the full spectrum of dysplasia in all age groups. With use of MRI, Waters et al. classified glenohumeral dysplasia into types I to VII on the basis of humeral head position and glenohumeral deformation in patients ranging in age from 9 months to 14 years[4]. Measurement parameters including glenoid version and the PHHA on MRI have been validated in this population[20,21]. Because of the comparative ease of obtaining ultrasound studies, the use of ultrasonography has been expanded to include older patients[13,22]. The evidence to support such use, however, is lacking.

Zhang and Ezaki reported on the use of ultrasonography among 146 patients ranging in age from 2 months to 3 years (average, 8 months)[22]. Ultrasound was used as a confirmatory study after the clinical diagnosis of posterior humeral head dislocation had been made and was often the only imaging study before surgical treatment. Despite a wide variation in scanning times (5 to 60 minutes), the authors recommended ultrasound as the modality of choice for diagnosing dysplasia in children up to 3 years of age. Other studies have questioned the sensitivity of ultrasonography in the evaluation of older children. Saifuddin et al. correlated ultrasound scans with intraoperative findings for 22 children 0.83 to 13.92 years of age[13]. The authors found that ultrasound had an 18% false-negative rate in the diagnosis of glenohumeral incongruity in this population. They cautioned that ultrasonography could not always distinguish between a congruent joint and a joint in which the humeral head is located within a well-formed pseudoglenoid.

The calculation of the alpha angle and the PHHD requires precise identification of the posterolateral aspect of the glenoid. This point is used to define the alpha angle apex and the posterior scapular line for the PHHD. Increasing glenoid retroversion and osseous deformation can make it challenging to accurately identify this point. The lower resolution of ultrasound makes it difficult to interpret the contour of the glenoid or reference adjacent soft-tissue structures such as the labrum and the posterior capsule. Although we found good to excellent intrarater and interrater reliability for the alpha angle and the PHHD on both MRI and ultrasound, the agreement between imaging techniques was poor. This implies that the evaluators consistently defined important points such as the posterolateral aspect of the glenoid in different locations with each imaging modality. Increasing deformity may make ultrasound more likely to misrepresent the accurate location of the posterolateral aspect of the glenoid. This is especially true in patients with glenoid biconcavity, rounding of the posterior osseous lip, or extreme retroversion. This concept is supported by our finding of increased MRI-ultrasound measurement difference in older children, who more commonly have these features of deformity. The upslope of the posterior aspect of the scapula is another confounding factor that may affect ultrasound measurement. What could be appreciated on MRI and not on ultrasound was that the scapular body remodels to support the dysplastic glenoid, in effect, minimizing the apparent deformity.

Although we previously thought that glenoid version could be estimated on ultrasound, the current study does not support this concept[23]. We found poor interrater reliability for measurements of glenoid version in this population. This may be explained by the study's inclusion of older children in whom deformity was greater and for whom ultrasound provided less resolution of the anterior aspect of the glenoid. Although PHHD measurements are not typically made on MRI, our study found better interrater reliability for this measurement than for the PHHA. This may be explained by the difficulty of defining the glenoscapular axis when given the entire MRI sequence. This is consistent with the findings of van der Sluijs et al., who reported decreased interobserver reliability when measuring humeral head displacement relative to the glenoscapular axis. The authors attributed this discrepancy to differences in MRI slice selection[21].

One weakness of the current study was the time interval between ultrasound and MRI studies, which ideally should have been performed on the same day. However, our data showed no gains in agreement between modalities when comparing only the studies performed within 1 month of each other. Another potential cause of the discrepancy between MRI and ultrasound measurements may be that MRI is typically obtained along the axis of the thorax, not the scapular body, whereas ultrasound images are typically in the plane of the scapula because the operator can adjust for scapular position. There is also the possibility that supine positioning and muscle relaxation during MRI may have affected the humeral head position.

In conclusion, MRI and ultrasound measurements demonstrated excellent intrarater and interrater reliability for many parameters. However, the poor agreement between MRI and ultrasound measurements calls into question the validity of using ultrasound as a stand-alone examination method for glenohumeral dysplasia. Deformity at the posterolateral aspect of the glenoid may cause ultrasound measurements to misrepresent humeral head position. MRI therefore remains the gold standard to fully evaluate the glenohumeral joint. The role of ultrasound in our practice has shifted to use in (1) determining if the humeral head can be translated anteriorly with external rotation and (2) categorizing the glenohumeral joint as normal, dysplastic, or dislocated. This study has demonstrated that ultrasound is not a valid tool for measuring progressive humeral head subluxation for patients >1 year of age or patients with substantial glenoid deformity.

Appendix

eA A description of the measurement technique for each parameter (alpha angle, PHHD, glenoid version, and PHHA) is available with the online version of this article as a data supplement at jbjs.org. ■

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