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PEDIATRIC RADIOLOGY

ORIGINAL ARTICLE

Value of shoulder US compared to MRI in infants with obstetric brachial plexus paralysis

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PURPOSE
Children with brachial plexus birth injury (BPBI) may eventually develop glenohumeral instability due to development of unbalanced muscular strength. Our major goal in this study is to compare the accuracy of physical examination and ultrasonography (US) in determination of glenohumeral instability in infants with BPBI compared with magnetic resonance imaging (MRI) as a gold standard, and to investigate the role and value of US as a screening modality for assessing glenohumeral instability.

METHODS
Forty-two consecutive patients (mean age, 2.3±0.8 months) with BPBI were enrolled into this prospective study. Patients were followed up with physical examination and US with dynamic evaluation in 4–6 weeks intervals. Patients who developed glenohumeral instability based on physical examination and/or US (n=21) underwent MRI. Glenohumeral instability was defined as alpha angle >30° and percentage of posterior humeral head displacement >50%. Diagnostic accuracy of physical examination and US was calculated and quantitative parameters were compared with Wilcoxon test.

RESULTS
Glenohumeral instability was confirmed with MRI in 15 of 21 patients. Accuracy and sensitivity of physical examination and US were 47%, 66% and 100%, 100%, respectively in determination of glenohumeral instability. No significant difference was found for the alpha angle ($p = 0.173$) but the percentage of posterior humeral head displacement was statistically significant between US and MRI ($p = 0.028$).

CONCLUSION
Our results indicate that US with dynamic evaluation is a good alternative for MRI in assessment of glenohumeral instability in infants with BPBI, since it is highly accurate and specific, and quantitative measurements used for glenohumeral instability were comparable to MRI. US can be used as a screening method to assess glenohumeral instability in infants with BPBI.

Children with brachial plexus birth injury (BPBI) may eventually develop glenohumeral instability (GI) due to development of unbalanced muscular strength. Shoulder related problems in patients with BPBI include internal rotation contracture, impaired physeal growth, and articular changes (glenoid retroversion and posterior glenoid deformation) (1, 2). Despite the fact that GI is most commonly believed to develop gradually after birth, the exact timing is not clear (3, 4). In order to prevent the development of osseous deformity, early diagnosis and intervention of GI is critical (5–7). Recent studies showed that development of GI can be detected with ultrasonography (US) as early as 3 months of age (8, 9). Clinical diagnosis of GI can be challenging and imaging modalities are important for the evaluation of stability of the joint (2). Because of the lack of ossification in the humeral head and glenoid, conventional radiographs and computerized tomography have only minor roles in the assessment of GI (10, 11). Although magnetic resonance imaging (MRI) is the current gold standard imaging modality for dysplasia in the whole age spectrum, US is also a very promising modality that can be used for this purpose. Since it is cost effective and, unlike MRI, requires no anesthesia, frequent follow-up examinations are possible with US (1, 2, 9, 12, 13). Furthermore, it is also possible to perform dynamic examination and assess the reducibility of the humeral head with US (13), which can be used as a good indicator

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for GI. In the literature, a variety of quantitative parameters has been used to assess the presence of GI but the alpha (α) angle and the percentage of posterior humeral head displacement (PPHHD) are the most valuable parameters for overall evaluation of the GI (2, 12, 14). Intra- and interobserver reliability of these measurements was shown to be good to excellent for US (12, 15) but there was poor agreement between US and MRI (15).

The major goal of our study is to compare the accuracy of primary physical examination and US in infants with BPBI and determine whether the diagnostic success of US is comparable to MRI, the current gold standard modality. In addition, the secondary objective of this study is to assess the agreement between US and MRI measurements for detecting GI in this patient population.

Methods

The study was approved by the local ethics committee (GO 16/409–29) and written informed consent was acquired from the legal guardians of all patients. Between June 1, 2017, and June 1, 2019, 42 patients (girls/boys, 23/19; mean age, 2.3±0.8 months; age range, 1–4 months) who were referred from the Department of Orthopedics and Traumatology with the clinical diagnosis of BPBI were prospectively included to this study. We excluded the patients who underwent surgery for GI or BPBI (n=5) and those who did not have regular follow-ups (n=3).

Ultrasound

All US examinations were performed by an experienced radiologist with 7 years of experience in pediatric and musculoskeletal imaging (A.G., US_1) who was blinded to physical examination findings. High-frequency linear probe (Sonoline G40, Siemens [5–7.5 MHz]; Xario, Toshiba [5–12 MHz]) were used for imaging examination with patient lying on contralateral (unaffected) side (decubitus) and/or erect position (the child held on the mother's shoulder) without specific preparation or sedation for US. The duration of the examination was about 5 minutes. Posterior approach was used and all shoulders were imaged in axial plane, with the upper arm adducted and elbow flexed to 90° in maximal internal rotation (13). During dynamic evaluation, reduction of humeral head towards the glenoid fossa during passive maximal external rotation was assessed.

The α angle was defined as the angle between the intersection of the posterior scapular margin with an imaginary line tangential to the humeral head through the posterior echogenic glenoid labrum; PPHHD was defined as the percentage of the humeral head posterior to the posterior scapular margin (10, 16) (Fig. 1). All images required for quantitative US measurements, as well as an image in passive maximal external rotation for the assessment of the reducibility of the humeral head were saved in the picture archiving and communication system.

Main points

- Children with brachial plexus birth injury may eventually develop glenohumeral instability possibly due to unbalanced muscular strength.
- Ultrasonography is a useful imaging modality for the evaluation of glenohumeral instability in patients with brachial plexus birth injury due to high accuracy rate in determination of instability compared with MRI and surgical findings.
- Periodical patient follow-up with US may help to detect glenohumeral instability earlier than it can be detected clinically.

MRI

All MRI examinations were done with 1.5 T scanner (Symphony, Siemens or GE Healthcare) with the flex coil. The patients were placed in supine position with the affected arm and shoulder kept in the same position as in the US exams. Intravenous gadolinium-based contrast agent was not used. The imaging technique included an axial and coronal-oblique T1-weighted spin-echo (TR/TE, 450–600/12–15 ms; FOV 16 cm; section thickness/gap, 3/1 mm), axial and coronal fat-suppressed proton density (TR/TE, 2300–2800/40 ms; FOV 16–18 cm; section thickness/gap, 0.7–1/0.5 mm) sequences. The acquisition time was approximately 20–25 minutes including the administration of sedative/anesthetic agent.

Image interpretation

Shoulders were classified as being either stable if α ≤30° and PPHHD ≤50% or instable if α >30° and PPHHD >50% on US (2, 17, 18). Reduction of humeral head towards the glenoid fossa during passive maximal external rotation was interpreted as a finding for GI. A second radiologist (E.G., US_2, 6 years of experience in US and musculoskeletal imaging), who was also blinded to the physical examination findings, independently measured α angle and PPHHD from stored US images on the picture archiving and communication system.

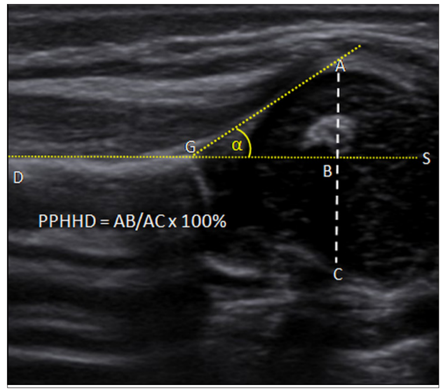

Figure 1. Transverse US images show the measurement of alpha angle (α) and percentage posterior humeral head displacement (PPHHD). The α angle is formed by the posterior scapular margin (S) and a line tangent to the humeral head passing through the posterior echogenic glenoid labrum (G). The PPHHD is the percentage of the humeral head posterior to the posterior scapular margin (S).

MRI measurements (α angle and PPHHD) were performed by the third radiologist (A.A., MRI; 8 years of experience in musculoskeletal imaging) who was blinded to the physical examination and US results. Stable and instable shoulders were determined according to the same criteria that were used for US (i.e., stable if α ≤30° and PPHHD ≤50% or instable if α >30° and PPHHD >50%). Also, on MRI, comparison of paraspinal muscles, the thickness of the rotator cuff muscle, the presence of an abnormal amount of intramuscular fatty infiltration, and glenoid configuration were assessed visually.

Physical examination

All physical examinations were performed by one experienced pediatric orthopedic surgeon (A.U.; with 11 years of experience in managing BPBI). Based on Narakas classification, there were 20 patients with grade 1, 16 patients with grade 2, and 6 patients with grade 3 BPBI (19). The clinical diagnosis of GI was made by a combination of examination of the posture of the limb, internal rotation contracture, and posterior humeral head prominence-palpation of the shoulder, axillary-fold asymmetry, and measurement of the range of passive lateral rotation.

Follow-up strategy

All patients were followed at 4–6 weeks interval with physical examination and US.

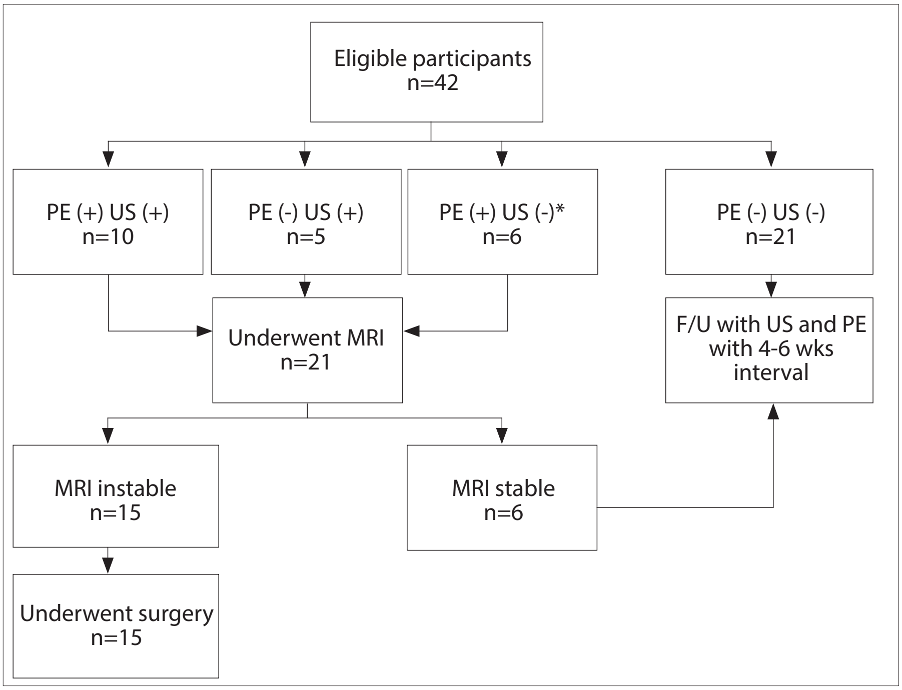

Figure 2. Flow chart representing the follow-up strategy of the patients. * Six patients with glenohumeral instability based on physical examination but stable on US findings underwent MRI.

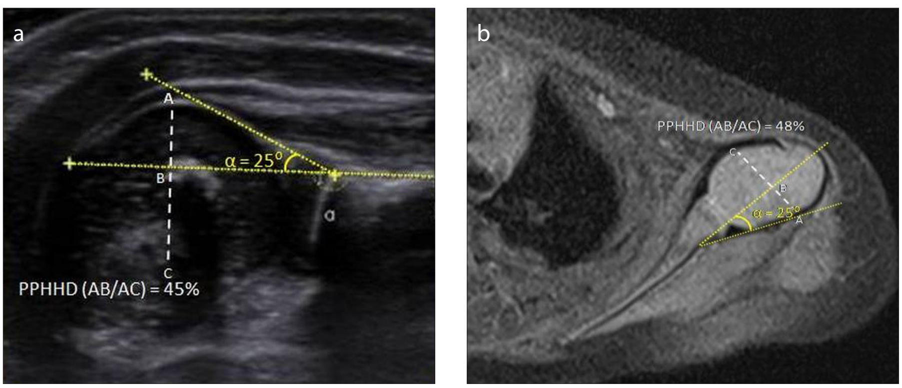

Figure 3. a, b. Case 6, a 2-month-old boy with left brachial plexus birth injury. Transverse US **(a)** and axial MRI **(b)** images both demonstrate α <30° and PPHHD <50% which was interpreted as stable.

Patients who did not develop GI depending on physical examination and/or US findings were followed up until one year of age with only physical examination and US (Fig. 2). The patients who developed GI depending on physical examination and/or US findings underwent MRI during follow-up. If patients had GI according to MRI findings, they underwent surgery to maintain the biomechanics of the shoulder with operative techniques of tendon release and/or transfer, and relocation.

Statistical analysis

The numerical variables were expressed as mean ± standard deviation (minimum–maximum), or median (interquartile range, IQR). The categorical variables were expressed as number and percentage. The sensitivity, specificity, and accuracy of GI detection were calculated for both physical examination and US (performed by the orthopedic surgeon and US_1) using a 2×2 table based on the MRI findings. Wilcoxon test was used for comparison of dependent numerical variables between US (performed by US_1) and MRI. For US, intra- and interobserver agreements for each quantitative parameter were calculated using the intraclass correlation coefficient (ICC) between observers. The ICC values were interpreted as follows: <0.40, poor-to-fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement, and 0.81–1.00, almost perfect agreement. The statistical analysis was conducted with statistical software (SPSS, version 21.0; IBM Corp.) and $p < 0.05$ was considered statistically significant. A power analysis using the software G*Power (Faul&Erdfelder, 1992) indicated that a total sample of 19 patients would be needed to detect large effects (d =0.8) with 90% power using a t test between means with α at 0.05. However, in order to secure the number of samples, the sample size was increased and 42 patients were planned in our study. We conducted post hoc power analyses using the software G*Power with power (1-β) set at 0.80 and α = 0.05 for 42 patients.

Results

A total of 350 examinations were performed in patients with (n=44) and without (n=306) GI during the follow-up of 42 infants. The average age of the infants at the time of the initial US exam was 2.3±0.8 months (1–4 months), and in the initial US examination all patients were stable in terms of quantitative US parameters and dynamic US evaluation. Demographic characteristics, Narakas classification, US and MRI measurements of patients are presented in Tables 1 and 2.

During the follow-up, 21 patients with GI based on physical examination and/or US evaluation underwent MRI (Fig. 2). On MRI, GI was detected in 15 of these patients (10 patients referred based on physical examination and US findings; five patients referred based on US findings, but stable on physical examination findings). In six of 21 patients, although GI was detected in the physical examination, no GI was detected on US and MRI (Fig. 2). In 15 patients with confirmed GI on MRI, the mean age at presentation was 2.9±0.7 months (2–4 months). The diagnosis of GI was established at a mean age of 5.7±0.6 months (4.5–7 months) on US and 5.9±0.6 months (4.5–7 months) on MRI. The average time between US and MRI was 0.2±0.3 months (0–1 month) (Figs. 3, 4). Instability developed in 2nd (n=4), 3rd (n=8), and 4th (n=3) US follow-up and detected earlier than 6 months of age in 8 of 15 patients (53.3%) (Table 3). All patients with GI (n=15) had reduction of the humeral head with the passive external rotation of the shoulder during dynamic evaluation with US. Posterior subluxation of the humeral head is visually assessed during the maneuver and if the humeral head was reduced

Table 1. Demographic characteristics and quantitative measurements of the patients with glenohumeral instability at the time of determination of instability

				US_1		US_2		MRI	
Case	Sex	Age (m)	N group	α	PPHHD	α	PPHHD	α	PPHHD
1	F	2	1	21	48	26	41	24	38
2	M	1.5	1	18	47	26	40	20	41
3	M	1	1	24	46	18	42	22	41
4	M	1	1	26	45	20	38	28	48
5	M	2	1	28	47	27	42	27	40
6	M	2	2	25	45	24	48	25	48
7*	M	3	2	35	63	36	68	34	67
8*	M	4	1	34	60	36	52	35	52
9*	M	3.5	2	33	56	35	63	34	59
10*	M	4	2	34	58	36	53	35	52
11*	M	2	1	33	54	34	62	34	58
12*	F	2.5	2	33	55	33	61	35	62
13*	M	3	1	34	59	36	64	33	52
14*	M	2.5	2	35	58	36	52	33	52
15*	F	3	2	33	55	34	62	35	59
16*	F	2	2	34	57	35	64	33	52
17*	M	2	1	34	60	35	53	36	52
18*	F	4	1	33	54	34	62	35	58
19*	F	3	3	32	59	33	53	33	52
20*	F	3	2	34	60	35	52	34	52
21*	F	2.5	2	35	54	35	62	33	59

N, Narakas classification; US_1/US_2, ultrasonography by examiners 1 and 2; MRI, magnetic resonance imaging; m, months; α, alpha angle; PPHHD, percentage of posterior humeral head displacement; F, female; M, male.
*Patient underwent surgery.

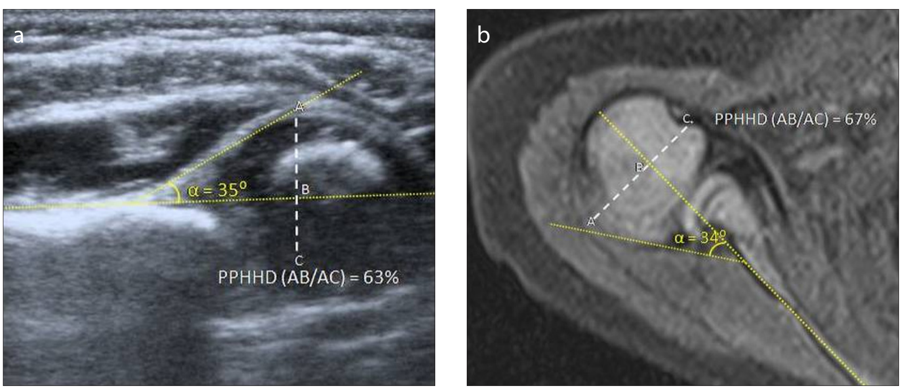

Figure 4. a, b. Case 7, a 3-month-old boy with right brachial plexus birth injury. Transverse US **(a)** and axial MRI **(b)** images show posterior subluxation of the left shoulder α >30º and PPHHD >50%. The shoulder was found to be instable at surgery.

in glenoid fossa normalization of α angle and PPHHD values were noted (Fig. 5). Six patients who were instable depending on physical examination but stable on US were diagnosed as stable on MRI and they were followed in 4–6 weeks intervals up to one year of age.

On MRI, muscle atrophy and intramuscular fatty degeneration was noted in all rotator cuff muscles, most severely in the subscapular muscle. The glenoid configuration was flat in 14 patients and the posterior margin of the glenoid demonstrated concavity in seven patients.

In diagnosis of instability, accuracy, sensitivity, and specificity values were 100%, 100%, 100% for US and 47%, 66%, 0% for physical examination, in 21 patients who underwent MRI. For the assessment of stability, the concordance rate for US and MRI (both for US_1 and US_2) was 100%. Between US and MRI, no significant difference was found for the α angle (33°, IQR 27°–34° vs. 33°, IQR 27.5°–35°; $p = 0.173$); but a significant difference was noted for the PPHHD (55%, IQR 47.5%–59% vs. 52%, IQR 48%–58.5%; $p = 0.028$). Compared with MRI, the measurements made on US underestimated the α angle and overestimated the PPHHD by an average of 0.4°±1.5° and 2.1%±5.7%, respectively. Interobserver agreement was almost perfect for the α angle and substantial for the PPHHD (ICC, 0.95, 0.79, respectively, $p < 0.001$) for US. Intraobserver agreements were found to be perfect for the α angle and the PPHHD (ICC range, 0.84–0.97, $p < 0.001$) (Table 4).

Table 2. The demographic characteristics and US findings of the patients without glenohumeral instability at the time of initial presentation

Case	Sex	Age (m)	N group	US_1		US_2	
				α	PPHHD	α	PPHHD
1	F	3	2	20	46	22	38
2	F	2	1	22	47	23	41
3	F	2.5	3	23	45	20	48
4	F	2	1	24	47	21	38
5	M	3	1	23	46	22	37
6	F	2	2	24	38	24	48
7	F	1.5	1	26	48	25	40
8	M	2	1	25	46	26	36
9	F	1.5	1	26	47	24	39
10	F	1	2	27	46	26	38
11	F	1	1	26	48	24	41
12	M	2	1	24	46	23	36
13	M	4	2	23	40	24	48
14	F	2	1	22	47	24	38
15	F	2	1	21	46	20	35
16	F	1.5	2	20	48	19	39
17	F	1.5	1	21	46	18	38
18	F	2	2	22	45	20	37
19	M	3	1	23	46	20	47
20	F	4	1	24	47	21	38
21	F	2.5	1	22	46	23	36

N, Narakas classification; US_1/US_2, ultrasonography by examiners 1 and 2; m, months; α, alpha angle; PPHHD, percentage of posterior humeral head displacement; F, female; M, male.

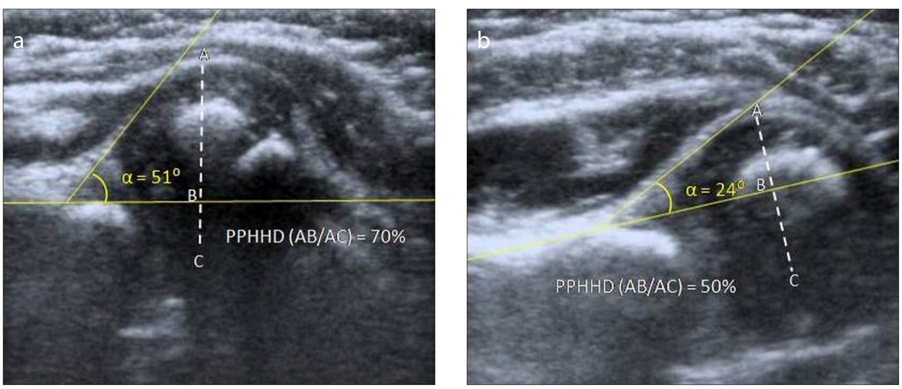

Figure 5. a, b. Case 14, a 2.5-month-old boy with right brachial plexus birth injury. Transverse US image **(a)** shows posterior subluxation of the shoulder α >30º and PPHHD >50%. In panel **(b)**, dynamic evaluation revealed normalization of measurements (α <30º and PPHHD <50%).

The post hoc analyses showed that the statistical power for this study was 0.65 for detecting a small effect, whereas the power exceeded 0.99 for detecting a moderate-to-large effect.

All patients with GI underwent surgery (mean time to surgery, 6.6±1.1 months; range, 5–9 months; tendon release [n=15], tendon transfer [n=1]) and all cases were diagnosed as instable during surgical exploration.

Discussion

In this study we found higher accuracy and specificity rates (100% and 100%) of US compared with physical examination (47% and 0%) in patients with confirmed GI on MRI. For the assessment of stability, the concordance rate of US (both for US_1 and US_2) and MRI was 100%. Our results indicate that US can be used as a screening tool and detect GI in infants with BPBI as early as 4.5 months of age.

Development of glenohumeral joint deformity has been shown to be related with increasing age in patients with BPBI (1, 2, 14, 20, 21). Previous studies reported that the initial deformation of glenoid cavity and the humeral head develops in approximately the fifth month of life and secondary changes such as retroversion of the glenoid, posterior edge loss with thinning of glenoid cartilage, smaller humeral head size can be detected before the first year of life in patients with BPBI (1, 14, 20, 21). In a more recent study by Pöyhiä et al. (9), authors prospectively examined 132 patients with BPBI, and 27 who did not clinically regress during the first year of life underwent US, in 1st, 3rd, 6th, and 12th months of age. They concluded that in cases with persisting symptoms, US should be done between 3–6 months of age for detecting posteriorly subluxed humeral head and shoulder instability (9). In another study by Moukoko et al. (8), authors reviewed 134 patients with BPBI for the assessment of GI with physical examination and when abnormal findings were recognized with physical examination, US was performed. They have shown that GI can be detected within a mean age of 6 months (age range, 3–10 months) (8). The results that we found in this study are in partial agreement with the other studies in the literature (8, 9); in the presented study, we detected GI as early as 4.5 months of age and at 7 months the latest. Unlike Pöyhiä and Moukoko's studies (8, 9), we did not wait for physical examination findings to develop for performing US. Additionally, all patients who developed instability depending on physical examination and/or US underwent MRI examination, which is currently considered as the gold standard examination.

In our study, no false-negative or false-positive interpretation has been made with US in patients with MRI-confirmed GI. In a study by Saifuddin et al. (5), authors examined 22 patients—with a mean age of 4.7 years—with chronic BPBI using US for the congruity shoulders and compared with surgical findings. In their study, US failed to demonstrate shoulder

Table 3. Follow-up US and physical examination findings of the patients who developed glenohumeral instability

Case	Sex	N group	Age–initial (m)	Age–GI dx (m)	FU1		FU2		FU3		FU4	
					US	PE	US	PE	US	PE	US	PE
1	M	2	3	4.5	–	–	+	+				
2	M	1	4	5.5	–	–	+	–				
3	M	2	3.5	5	–	–	+	–				
4	M	2	4	5.5	–	–	+	+				
5	M	1	2	5	–	–	–	–	+	–		
6	F	2	2.5	5.5	–	–	–	–	+	+		
7	M	1	3	6	–	–	–	–	+	+		
8	M	2	2.5	7	–	–	–	–	–	–	+	+
9	F	2	3	6	–	–	–	–	–	–	+	+
10	F	2	2	6	–	–	–	–	–	–	+	+
11	M	1	2	6	–	–	–	–	+	+		
12	F	1	4	6.5	–	–	–	–	+	–		
13	F	3	3	6	–	–	–	–	+	–		
14	F	2	3	5.5	–	–	–	–	+	+		
15	F	2	2.5	5.5	–	–	–	–	+	+		

F, female; M, male; N, Narakas classification; m, months; GI, glenohumeral instability; dx, diagnosis; FU, follow-up; US, ultrasonography; PE, physical examination.

Table 4. Intraobserver agreement for each measurement

	US_1	US_2	MRI
	ICC (95% CI)		
Alpha angle	0.92 (0.86–0.96)	0.97(0.95–0.98)	0.94 (0.86–0.97)
PPHHD	0.87 (0.76–0.93)	0.84 (0.70–0.91)	0.96 (0.91–0.98)

US_1/US_2, ultrasonography by examiners 1 and 2; MRI, magnetic resonance imaging; ICC, intraclass correlation coefficient; CI, confidence interval; PPHHD, percentage posterior humeral head displacement.

incongruity in three patients and therefore the diagnostic accuracy of US for the identification of shoulder incongruity was 82%, whereas in our study it was 100% (5).

In our study, in five patients (33%) with MRI-confirmed GI, instability was detected only with US (5 to 6.5 months) but not with physical examination. Similarly, Pöyhiä et al. (9) reported that in 16% of patients with US-verified GI, instability was not clinically detectable. They did not mention the mean age of these patients. Additionally, in our study, six patients who were instable on physical examination but stable on US turned out to be stable on MRI. Therefore, it can be suggested that physical examination can be misleading and performing earlier US examination in the course of the disease should be considered for more accurate evaluation.

In a study by Kenneth et al. (15), authors investigated the agreement between measurements (α angle and PPHHD) acquired on US exams and those obtained with MRI for assessing glenohumeral dysplasia BBPI in 39 patients. They stated that compared with MRI, US underestimated the α angle by 13°±25° and overestimated the PPHHD by 4%±20%, suggesting a low level of agreement between MRI and US. In the same study, authors analyzed the effect of patient age on MRI-US agreement and they found a closer agreement for α angle in subjects who were less than 1 year of age (8°±18°) and noted that there is a positive relationship between increased patient age and a prominent increase in the MRI-US measurement difference for α angle and minor increase in the difference for the PPHHD. The difference was explained by the progressing glenoid deformity with the advancing age, which makes visualization of posterolateral part of the glenoid more difficult with US, resulting in underestimation of α angle (15). In our study, US underestimated the α angle by 0.4°±1.5° and overestimated the PPHHD by 2.1%±5.7%. Since the mean age of our patient population was much lower than in Kenneth et al. (15) (2.9 vs. 20 months), α angle findings were more comparable, as also suggested in their study for patients <1 year of age.

In this study, the α angle measurements did not differ significantly between US and MRI, but there was statistically significant difference in terms of PPHHD. The difference in PPHHD may be explained by the inadequate visualization of the largest dimension of the humeral head due to shadowing from the ossification centers within the humeral heads (as shown in Figs. 3a, 4a, and 5) and medial segment of the scapula on the same plane with US compared with MRI. Although the quantitative measurements of PPHHD differ between US and MRI, overall detection rate of GI with US did not appear to be adversely affected in our study considering the high concordance rate in detection of GI with US compared with MRI.

In the present study, interobserver agreement for US measurements was excellent for the α angle and substantial for the PPHHD. Vathana et al. (12) evaluated interobserver agreement of US in the shoulders of infants with and without clinically suspected posterior shoulder dislocation resulting from BPBI and similar to our study they found excellent interobserver agreement for the α angle (ICC, 0.87) and substantial for the PPHHD (ICC, 0.77) and concluded that US examination of the shoulder is a trustworthy technique for determining humeral head position in infants with BPBI. Similar to our findings, Kenneth et al. (15) found excellent interobserver agreement for the α angle (ICC, 0.78) and substantial for the PPHHD (ICC, 0.68) for US.

The advantage of US over MRI is that dynamic US examination can be used to determine whether the humeral head is amenable to reduction. In our study, the reduction of humeral head towards the glenoid fossa was noted in all patients with confirmed GI, in the same way mentioned in previous studies (9, 12). The main points that may increase the value of our study are its prospective nature, meticulous imaging follow-up with physical examination and US, and the surgical findings for comparison. Our study differs from the previous studies in several ways. In the present study, US was used as the initial diagnostic tool without previous screening and for follow-up of patients for GI. In other studies assessing the value of US in patients with BPBI, follow-up intervals were longer (2 to 6 months) compared to our study (4–6 weeks), which provided more precise monitoring of GI development (6, 9, 12, 15). The time interval between US and MRI was shorter (up to one month) compared with other studies (range, 0–6 months) (15).

There are some limitations to our study: first, not all patients had shoulder MRI for comparison with US, since it was not possible to perform MRI in patients who have no findings of instability with US or physical examination. If all patients had shoulder MRI, the specificity of physical examination would be different than what we found (0%) and we must stress that sensitivity of physical examination in detecting GI is underestimated in this study; second, all sonographic examinations were done by the same experienced radiologist in pediatric imaging. As this is a clinical research study, it was not possible to get the patients once again for US examinations in the same visit during follow-ups (a separate consent from the legal guardians of all patients would also be, then, necessary). As is well-known US is highly operator dependent. We should also highlight that high interobserver reliability about measurements using US may be overestimated in our study (as the second radiologist used only the static images that are stored in picture archiving and communication system and did not personally perform US examinations) and finally physical examination was performed only by one orthopedic surgeon.

Although comprehensive evaluation of glenohumeral joint may not be optimal with US due its inherent limitation in evaluating the osseous and soft tissue anatomy as compared to MRI and its inherent operator dependence, we believe that these disadvantages can be eliminated by accessible regular follow-ups of the patients with US. Additionally, as with developmental dysplasia of the hip, we think that GI can also be detected with dynamic US examination by assessing reducibility of the humeral head or posterior subluxation of the humeral head by performing passive internal and external rotation of the shoulder. Previous studies and our study have shown that development of glenohumeral joint deformity and/or GI can be detected before the first year of life in patients with BPBI (1, 8, 9, 14, 20, 21). In order to prevent this deformity, early diagnosis and intervention to restore shoulder instability is critical (5–7). We think that follow-up of patients based solely on clinical findings is not sufficient and early US examinations should be performed for better clinical outcomes. US can be used as the initial diagnostic tool both for screening and follow-up of these patients between 3–12 months of age, similar to the use of US for developmental hip dysplasia.

In conclusion, our results showed that US with dynamic evaluation is a useful imaging modality for the evaluation of GI in patients with BPBI under the age of one. The accuracy of US for detection of GI was better than physical examination and high compared with MRI. Therefore US can be used as a screening method to assess GI in infants with BPBI and US can be a good alternative to MRI due to its easier application and availability, and the high interobserver agreement for quantitative parameters.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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