International Journal of General Medicine

Dovepress

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ORIGINAL RESEARCH

Value of High-Resolution MRI in the Diagnosis of Brachial Plexus Injury in Infants and Young Children

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Purpose: To investigate the value of high-resolution MRI based on 3D-short inversion time inversion recovery sampling perfection with application-optimized contrasts (3D-STIR SPACE) sequence for the diagnosis of brachial plexus injury in infants and young children.

Methods: Physical examination, electromyography (EMG) and MRI data of 26 children with brachial plexus injury were retrospectively analyzed. Sensitivity, specificity, and accuracy were calculated for the three tests. The agreement among these examinations was analyzed with the Kappa test. P<0.05 was considered statistically significant.

Results: Of the 26 children, 3 cases had normal MRIs, 23 cases had unilateral brachial plexus injury diagnosed with MRI, and a total of 73 nerve roots and/or sheaths were involved. Among the 23 cases with aberrant MRI findings, there were 19 cases of nerve root thickening (42 nerve roots), 4 cases of nerve root sleeve expansion (5 nerve roots), 17 cases of pseudomeningeal cysts (34 nerve roots), 2 cases of nerve root loosening (2 nerve roots), 8 cases of nerve root dissection (11 nerve roots), 19 cases with increased nerve signal (43 nerve roots), and 9 cases with an increased signal of the muscles on the affected side. As for the diagnosis of brachial plexus injury, the sensitivity and the accuracy of physical examination, EMG and MRI were 0.92, 0.86, and 0.88, respectively. The agreement between MRI and physical examination was substantial (κ=0.780, P=0.000), as did the agreement between MRI and EMG (κ=0.611, P=0.005).

Conclusion: High-resolution MRI based on 3D-STIR SPACE sequence plays a role in the diagnosis and evaluation of brachial plexus injury in infants and young children. It can accurately identify the injured nerve and characterize related pathological alterations. Besides EMG and physical examination, it can be used as a valuable tool for screening and monitoring of brachial plexus injury in infants and children.

Keywords: brachial plexus, injury, MRI, children

Introduction

The brachial plexus nerve comprises cervical C5–C8 and T1 nerve roots.[1] The branches of the brachial plexus are predominantly distributed in the upper limbs, and their functions include controlling the movement and sensation of the upper limbs, shoulders, back and chest.[1–3] Brachial plexus injury impacts the sensation and movement of the innervated limbs. The incidence of brachial plexus injury in infants is reported to be approximately 0.05% to 0.145%, and is directly related to maternal body mass index and fetal presentation.[2,4] In the absence of prompt treatment, brachial plexus injury leads to functional impairment of the affected limb, or even lifelong disability. Three months following an injury is considered the golden period of recovery.[4] Therefore, early diagnosis, evaluation, and treatment play a critical role in the prognosis of these patients.

Traditional screening tools for brachial plexus injury include physical examination (muscle strength test), electromyography (EMG) and nerve root computed tomography (CT) imaging.[5] Regarding physical examination, infants and young children are difficult to examine due to their lack of cooperation, and the results are highly subjective, thereby compromising the accuracy of the results. EMG can determine the presence of brachial plexus injury and the location of the injury.[3] Nonetheless, it is an invasive examination and painful to the children. Examination conducted within the first

Received: 21 February 2022
Accepted: 13 June 2022
Published: 18 June 2022

three weeks is prone to negative results. Additionally, it is challenging for the children to perform corresponding physical movements during the examination. These affect the accuracy of the results. CT myelography was originally employed as the primary imaging tool and regarded as the gold standard for the diagnosis of brachial plexus injury.[1,5] It can display the type and degree of injury through axial and coronal reconstruction images. However, it cannot delineate the postganglionic nerve damage and is associated with X-ray radiation and the side effects of contrast agents. Hence, it is currently not utilized for the diagnosis of brachial plexus injury in infants and young children.

Magnetic resonance imaging (MRI) is widely used in adult brachial plexus imaging owing to its non-invasiveness, high soft-tissue resolution and multi-planar imaging.[1,6,7] It can clearly portray the traveling and abnormalities of nerves, blood vessels and adjacent muscles. Due to the small anatomical space and low contrast between tissues in the pediatric population, MRI is less effective in displaying the brachial plexus in children than in adults. Therefore, the diagnostic value of MRI in infants and young children with brachial plexus injury remains controversial. Besides, previous studies mainly focused on 2D sequences, and these studies were mainly performed with 1.5T MR scanners.

Fat suppression technique is critical in brachial plexus MRI.[8,9] 3D-short inversion time inversion recovery sampling perfection with application-optimized contrasts (3D-STIR SPACE) sequence can effectively suppress fat and perform multi-planar and curve-planar reconstruction.[6,10–12] This study aimed to use this MR technique to diagnose and evaluate brachial plexus injury in children, and compare the MRI results with those of physical examination and EMG. Our study may validate the benefits of the high-resolution MRI based on 3D-STIR SPACE sequence in children with brachial plexus injury.

Methods

Subjects

From July 2015 to April 2018, this study consecutively enrolled 28 children who were diagnosed with brachial plexus injury. Clinical signs and symptoms, history of birth injuries or trauma, physical examination (muscle strength test, carried out by one physician to ensure consistency of results), MRI and EMG data were collected. Two patients were excluded from this study because of poor MR image quality. EMG examination was not performed in five children under one month of age, but an MR examination was performed on the affected side based on the results of the physical examination in these children. Then, the physical examination, MRI and EMG data were retrospectively analyzed. Of these children, 22 were males, and 4 were females, ranging in age from 5 days to 5 years, with a mean age of 9.8 months. The clinical symptoms were dysactivity or paralysis, including 16 cases on the right side and 10 on the left side. None of the children underwent surgical treatment.

MR Scanning

MR images were performed using a 3.0T MR scanner (Siemens, Erlangen, Germany) with a 16-channel phased head-neck coil. The sequences and parameters were as follows. Sagittal T2WI: TR, 3500ms; TE, 98ms; number of excitations, 2; matrix, 256×384; FOV, 200×200mm; slice thickness, 4mm; slice spacing, 3mm. Axial T2WI: TR, 5380ms; TE, 91ms; number of excitations, 2; matrix, 320×256; FOV, 200×200; slice thickness, 4mm; slice spacing, 3mm. Axial T1WI: TR, 400ms; TE, 10ms; number of excitations, 2; matrix, 320×256; FOV, 200×200; slice thickness, 4mm; slice spacing, 3mm. Coronal 3D-STIR-SPACE sequence: TR, 3000ms; TE, 287ms; TI, 160ms; number of excitations, 2; slice thickness, 1mm; matrix, 320×320mm; FOV, 260×260. Following a plain coronal 3D-STIR-SPACE sequence scan, the children were injected with the contrast agent GD-DTPA into the cubital vein at a dose of 0.1 mmol/kg, and then underwent an enhanced coronal 3D-STIR -SPACE sequence scan. Children were sedated with a 10% chloral hydrate enema (0.5–1 mL/kg, total ≤10 mL/d).

Image Post-Processing and Analysis

In the 3D workstation, maximum intensity projection (MIP) and multiplanar reconstruction (MPR) were performed on the enhanced 3D-STIR-SPACE sequence images, and images that could directly display the brachial plexus were subsequently reconstructed. All MR images were reviewed on PACS by two experienced neuroradiologists blinded to the EMG and clinical physical examination data. The path, shape, signal, and surrounding structures of the brachial plexus were observed from various angles to determine whether the presence and location of the injury. When there was a difference in opinion, they discussed the issue until a consensus was reached.

Statistical Analysis

SPSS 19.0 statistical software was employed for data analysis. The classification data was described by frequency and composition ratio. Due to the lack of surgical outcomes, brachial plexus injury was ultimately diagnosed according to medical history, physical examination, EMG, MRI and clinical follow-up results, which are regarded as the gold standard for diagnosis. Hence, the sensitivity, specificity, and accuracy were calculated for physical examination, EMG, and MRI for the identification of brachial plexus injury using a 2×2 table based on the above standard. The Kappa test was used to measure the level of agreement between physical examination and EMG and MRI results. κ values between 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 0.8, and 0.8–1.0 indicated poor, fair, moderate, substantial, and almost perfect agreement, respectively. $P < 0.05$ was considered statistically significant.

Results

MRI Findings

Of the 26 cases, 3 had normal MRI findings, while 23 had abnormal MRI findings. Of the 23 cases with abnormal MRI findings, all were unilateral brachial plexus injuries, including 8 cases of left-sided injury and 15 cases of right-sided injury. Four cases had abnormal preganglionic nerve signals, 8 cases had abnormal postganglionic nerve signals, and 11 cases had both preganglionic nerve and postganglionic nerve signal abnormalities. A total of 73 nerve roots and/or sheaths were involved. There were 10, 21, 17, 15, and 10 nerve roots and/or sheaths involving the C5, 6, 7, 8, and T1 levels, respectively. MRI findings were as follows: (1) 19 cases (42 nerve roots) displayed nerve root thickening (Figures 1 and 2); (2) 4 cases (5 nerve roots) of nerve root sleeve expansion; (3) 2 cases (2 nerve roots) exhibited nerve root loosening, indicating nerve root avulsion without pseudomeningocele (Figures 1 and 2); (4) 8 cases (11 nerve roots) of nerve root dissection (Figures 1 and 2); (5) 19 cases (43 nerve roots) showed increased nerve signal (Figures 1 and 2); (6) 17 cases (34 nerve roots) of pseudomeningeal cysts (Figure 1), of which 9 cases (12 nerve roots) were accompanied by nerve root avulsion and 13 cases (22 nerve roots) with dural tear without nerve root tear. Nine cases showed increased muscle signal on the affected side (Figure 2). Children with brachial plexus injury may had one or more of the above MRI findings. Details of the findings are presented in Table 1.

Physical Examination

Among the 26 cases, 7 cases were graded 0 on muscle strength test (6 on the right side and 1 on the left side), 2 cases were graded 5 (1 on the left side and 1 on the right side), and the remaining 17 cases were graded 1–4 (10 right side and 7 left side), with an average grade of 2.00.

EMG

A total of 21 children underwent EMG examination. Sixteen cases exhibited denervation potential, non-detection of the motor unit potential of each muscle and non-elicitation of motor conduction velocity and F wave of peripheral nerve,

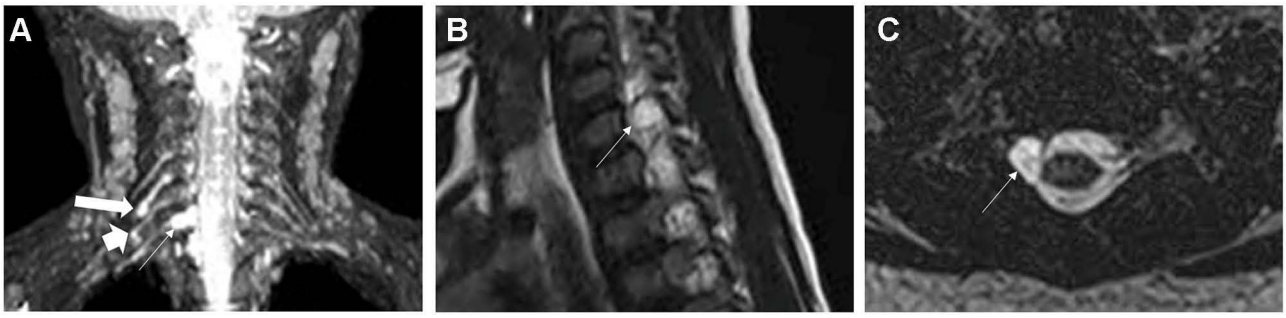

Figure 1 M, 37 months, right upper limb weakness for 3 months. Muscle strength was graded as I. EMG showed neurogenic damage to the right brachial plexus. Coronal MIP 3D-STIR SPACE image (**A**) displayed thickening of the right nerve root at C5 and C6 level (thick arrow), right nerve root loosening at C7 level (arrowhead), and right nerve root dissection at C8 level (thin arrow). Sagittal (**B**) and axial (**C**) T2WI showed pseudomeningocele at C8 level (thin arrow).

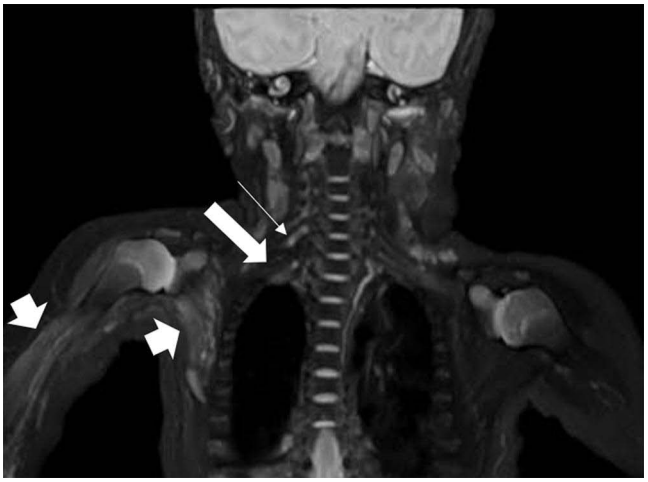

Figure 2 M, 34 days, right upper limb weakness for 1 month. Muscle strength was graded 0. EMG showed neurogenic damage to the right brachial plexus. Coronal 3D-STIR-SPACE image displayed thickening of the right nerve root at C5 and C6 level (thin arrow), right nerve root dissection at C7 and C8 level (thick arrow), and increased signal of right shoulder and upper limb muscles (arrowhead).

suggesting neurogenic damage. In two cases, the action potential amplitude of the musculocutaneous nerve and sensory nerve was diminished. Finally, EMG findings were normal in 3 cases.

Sensitivity, Specificity, and Accuracy of Different Examinations

With the patient as the unit of analysis, as for the diagnosis of brachial plexus injury via physical examination, both the sensitivity and the accuracy were 0.92, while the specificity was not estimable. In contrast, both the sensitivity and the

Table 1 Demographic, Clinical and MR Findings in 26 Patients

Findings		Numbers
Age (M)		9.8 ± 3.0
Sex (B/G)		22/4
Clinical symptoms (L/R)		10/16
Physical examination (P/N)		24/2
Electromyography (P/N)		18/3
MR findings (P/N)		23/3
Side	Unilateral (L/R)	23 (8/15)
	Bilateral	0
Type	Preganglionic	4
	Postganglionic	8
	Preganglionic and postganglionic	11
Location	C5	10
	C6	21
	C7	17
	C8	15
	T1	10
Specific findings	Nerve root thickening (NR)	19 (42)
	Nerve root sleeve expansion (NR)	4 (5)
	Nerve root loosening (NR)	2 (2)
	Nerve root dissection (NR)	8 (11)
	Increased nerve signal (NR)	19 (43)
	Pseudomeningeal cyst (NR)	17 (34)
	Increased muscle signal	9

Abbreviations: M, month; B, boy; G, girl; L, left; R, right; P, positive; N, negative; NR, nerve root.

Table 2 Sensitivity, Specificity and Accuracy of Physical Examination, EM and MRI for Brachial Plexus Injury with Patients as the Unit of Analysis

Tools	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	Accuracy (95% CI)
Physical examination	24	0	2	0	0.92 [0.73, 0.99]	Not estimable	0.92 [0.73, 0.99]
EMG	18	0	3	0	0.86 [0.63, 0.96]	Not estimable	0.86 [0.63, 0.96]
MRI	23	0	3	0	0.88 [0.69, 0.97]	Not estimable	0.88 [0.69, 0.97]

Abbreviations: CI, confidence interval; FN, false-negative; FP, false-positive; TN, true-negative; TP, true-positive.

accuracy of the EMG diagnosis of brachial plexus injury were 0.86, but the specificity could not be estimated. As for the MRI diagnosis of brachial plexus injury, both the sensitivity and the accuracy were 0.88, and the specificity was not estimable. Details of the findings are listed in Table 2.

Comparison Between Different Examinations

The agreement between brachial plexus MRI and physical examination was substantial (κ=0.780, P=0.000), as did the agreement between MRI and EMG (κ=0.611, P=0.005). In comparison, the agreement between physical examination and EMG was moderate (κ=0.462, P=0.012).

Discussion

In this retrospective study, the most common manifestations of brachial plexus injuries in infants and young children on high-resolution MRI were thickened nerve root, increased T2 signal, and pseudomeningeal cyst, whereas dilation of nerve root sleeves and prolapse of nerve roots were relatively rare. Regarding the diagnosis of brachial plexus injury, both the sensitivity and the accuracy of physical examination, EMG and MRI were 0.92, 0.86, and 0.88, respectively. Furthermore, the Kappa test uncovered that the results of the MR examination were in good agreement with those of the physical and EMG examinations. The aforementioned findings signal that brachial plexus MRI can assist in the early diagnosis and evaluation of brachial plexus injury in infants and young children.

MRI has been one of the most recommended imaging tools for detecting and diagnosing brachial plexus injury in recent years.[1,6,13] It can display the preganglionic and postganglionic nerves of the brachial plexus, as well as their surrounding structures. When a brachial plexus injury occurs, it can reveal not only tears of the nerve root but also the presence of spinal cord hemorrhage, edema, and meningocele. It has a great role in identifying the location and nature of brachial plexus injuries, and has been proved to be more accurate than CT myelography. MRI has been commonly used in brachial plexus imaging in adults. In recent years, it has been gradually used in infants and children.[14–17] Heavy T2 fat suppression technique and diffusion-weighted imaging are the most commonly used MR techniques.[9,18,19] The former has strict requirements on magnetic field strength and coil; thus, the latter is used more frequently. In this study, we used a 3D-STIR SPACE sequence based on the heavy T2 fat suppression technique on a 3T MR scanner to perform brachial plexus MRI examinations in infants and children with brachial plexus injury. This 3D sequence can be used for multi-planar and curved reconstruction, allowing for a thorough evaluation of the brachial plexus from multiple angles.

We noted that the thickening of nerve roots was the most prevalent direct sign of brachial plexus injury in infants and children, consistent with findings from previous studies on adult patients.[1,5,20] It indicates nerve root swelling in the acute stage, and neuroma or local scar formation in the chronic stage. Alterations in nerve root signals were another common direct sign herein, suggesting the presence of edema in the nerve. Pseudomeningocele is the most common indirect sign, and is commonly accompanied by nerve root avulsion.[15,21] It can also be caused by the laceration of the dura mater without nerve root avulsion. Nerve root prolapse is another sign of brachial plexus injury but is relatively rare. It indicates nerve root avulsion without pseudomeningocele. Some children had changes in the muscle signal of the affected side, suggesting the possibility of brachial plexus injury. It's worth noting that most of the children had multiple imaging findings.

In this study, we calculated the sensitivity, specificity, and accuracy of physical examination, EMG and MRI for the detection of brachial plexus injury and we exposed that the three examinations had comparable sensitivity and accuracy. Comparing the results of MRI with those of physical examination and EMG, it was determined that the results of MRI

were in good agreement with those of physical examination and EMG, in line with the finding of a previous study.[15] These results demonstrate the role of MRI in the diagnosis of brachial plexus injury. In infants and young children, the anatomical space is small, and the cross-sectional imaging contrast of the brachial plexus is poor, which hinders the localization and characterization of brachial plexus diseases. However, MRI findings such as thickening of nerve roots, enlarged nerve sheaths, and increased muscle signals do not disappear in a short period, making brachial plexus injury less likely to be misdiagnosed on MRI.

Some children with normal physical examination or EMG had abnormal MRI findings, which may be due to the short course of the disease or the younger age of the children. This suggests that MRI can detect brachial plexus injury earlier than physical examination and EMG. In addition, three cases with negative MRI findings had positive findings on physical examination or EMG, which may be attributable to mild brachial plexus injuries that did not result in anatomical changes. Therefore, the diagnosis of a brachial plexus injury needs to incorporate MRI, physical examination, and EMG results.

This study has some limitations which need to be considered. First, selection bias might have occurred due to the retrospective exclusion of two patients whose MRI images were suboptimal, and the retrospective study of medical tests tends to report inflated estimates of diagnostic accuracy.[7,22] Additional high-quality prospective studies are warranted in the future. Second, none of the children in this study underwent surgical treatment. Thus, MRI diagnosis lacked the gold standard from operative exploration. Lastly, the sequence used in this study could display anatomical changes in the brachial plexus but not neurofunctional information. Functional MRI and diffusion tensor imaging (fiber bundle imaging) can provide neurofunctional information for the diagnosis and treatment of brachial plexus injury,[23–25] and will be necessitated in future studies.

Conclusion

High-resolution MRI based on the 3D-STIR SPACE sequence plays a role in the diagnosis and evaluation of brachial plexus injury in infants and children. It can not only identify the injured nerve and determine the degree of injury, but also characterize the related pathological changes. It can be used for the early diagnosis, treatment and prognosis of brachial plexus injury. It has become an effective tool for the diagnosis of brachial plexus injury in infants and children, in conjunction with clinical physical examination and EMG.

Data Sharing Statement

All the data used to support the results of this study are available on request from the corresponding author.

Ethics Approval and Informed Consent

This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), and this study was approved by Institutional Review Board of Hangzhou Children's Hospital (No. 2019-07), and the requirement for written informed consent from the patients' parents was waived. The reasons for the waiver are as follows:

1. This study was not a prospective clinical trial and was a retrospective medical record data collection and analysis.
2. This study was the lowest risk, and the possible risk to the research subject did not exceed that of nonparticipating researchers, and the exemption from prior consent had no impact on the rights of the researcher.
3. Exempt informed consent did not affect the rights and wellbeing of the subject. Research could not be performed without exempting informed consent.
4. Appropriate privacy protection measures were in place to protect the children participating in the research.

Appropriate privacy protection measures were in place to protect the children participating in the research as follows:

1. This was a retrospective observational study, and the retrospective medical records do not involve the collection and use of specimens.
2. During data collection, the identities of the subjects were via the hospital inpatient information system.
3. We did not collect the name, history numbers, and other personal information of subjects in this study.

4. After the research was completed, all relevant data of the subjects participating in the research were destroyed according to law.

Acknowledgment

The authors thank Jing Han from the Department of Pediatrics who contributed to data collection and conduct of the study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was supported by the grant from Zhejiang Provincial Natural Science Foundation (LGF19H180003).

Disclosure

The authors report no conflicts of interest in this work.

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