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## Diagnostic performance of MRI and MR myelography in infants with a brachial plexus birth injury

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**Abstract** *Background:* Detailed evaluation of a brachial plexus birth injury is important for treatment planning. *Objective:* To determine the diagnostic performance of MRI and MR myelography in infants with a brachial plexus birth injury. *Materials and methods:* Included in the study were 31 children with perinatal brachial plexus injury who underwent surgical intervention. All patients had cervical and brachial plexus MRI. The standard of reference was the combination of intraoperative (1) surgical evaluation and (2) electrophysiological studies (motor evoked potentials, MEP, and somatosensory evoked potentials, SSEP), and (3) the evaluation of histopathological neuronal loss. MRI findings of cord lesion, pseudomeningocele, and post-traumatic neuroma were correlated with the standard of reference. Diagnostic performance characteristics including sensitivity and specificity were determined. *Results:* From June 2001 to March 2004, 31 children (mean age 7.3 months, standard deviation 1.6 months, range 4.8–12.1 months; 19 male, 12

female) with a brachial plexus birth injury who underwent surgical intervention were enrolled. Sensitivity and specificity of an MRI finding of post-traumatic neuroma were 97% (30/31) and 100% (31/31), respectively, using the contralateral normal brachial plexus as the control. However, MRI could not determine the exact anatomic area (i.e. trunk or division) of the post-traumatic brachial plexus neuroma injury. Sensitivity and specificity for an MRI finding of pseudomeningocele in determining exiting nerve injury were 50% and 100%, respectively, using MEP, and 44% and 80%, respectively, using SSEP as the standard of reference. MRI in infants could not image well the exiting nerve roots to determine consistently the presence or absence of definite avulsion. *Conclusion:* In children younger than 18 months with brachial plexus injury, the MRI finding of pseudomeningocele has a low sensitivity and a high specificity for nerve root avulsion. MRI and MR myelography cannot image well the exiting nerve roots to determine consistently the presence or absence of avulsion of nerve roots. The MRI finding of post-traumatic neuroma has a high sensitivity and specificity in determining the side of the brachial plexus injury but cannot reveal the exact anatomic area (i.e. trunk or division) involved. The information obtained is, however, useful to the surgeon during intraoperative evaluation of spinal nerve integrity for reconstruction.

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### Introduction

Perinatal traction-induced injuries of the brachial plexus can occur within the spinal canal or more distally at the level of the trunk, division or cord. Surgical management and prognosis of brachial plexus injuries depend on the precise diagnosis of the level, type and extent of the lesion. Advances in imaging, electrophysiological tests and microsurgical nerve repair techniques have allowed surgeons to achieve greater success in the management of brachial plexus injuries.

Brachial plexus imaging can be performed with MRI [1], CT myelography (CTM) and conventional myelography [2, 3]. MRI is a non-invasive multiplanar technique that allows detailed assessment of the cord and brachial plexus with no ionizing radiation or contrast material, in contrast to CTM and conventional myelography which both involve the risk of an adverse reaction to the contrast material, exposure to ionizing radiation and the risks associated with a lumbar puncture.

Although several studies have addressed the role of imaging or electrophysiological examination in patients with brachial plexus injury [1–4], few have addressed the overall role and diagnostic performance of MRI in children younger than 18 months with brachial plexus injury using the rigorous reference standard of intraoperative (1) surgical evaluation and (2) electrophysiological tests including motor evoked potentials (MEP) and somatosensory evoke potentials (SSEP), and (3) the evaluation of histopathological neuronal loss.

The purpose of this study was to determine the diagnostic performance (sensitivity and specificity) of the MRI findings using these standards of reference. Our hypothesis was that the MRI findings would be important in the evaluation of infants with brachial plexus injury but with certain limitations.

## Materials and methods

### Patient population and study design

Patients referred to the Brachial Plexus and Peripheral Nerve Surgery Program were enrolled prospectively. Inclusion criteria included children younger than 18 months with perinatal brachial plexus injury who had brachial plexus surgery. We obtained IRB approval. The standard of reference was the combination of intraoperative (1) surgical evaluation and (2) electrophysiological studies (MEP and SSEP), and (3) the evaluation of histopathological neuronal loss. No surgical laminectomies were done at the level of the cervical spine to determine direct avulsion of the nerve root because of increased morbidity and mortality from this procedure [5]. We determined nerve root integrity by intraoperative neurophysiological studies. We determined the degree of correlation between this

combined standard of reference and the MRI and MR myelographic findings. We calculated diagnostic performance characteristics including sensitivity and specificity.

### Intraoperative evaluation as standard of reference

The combined information from intraoperative surgical macroscopic evaluation, intraoperative neurophysiological tests, and histopathological findings was used as the standard of reference.

Intraoperative surgical macroscopic evaluation was done by the brachial plexus surgeon (J.A.I.G.). Intraoperative macroscopic evaluation included direct assessment of the brachial plexus injury. Direct surgical evaluation of the cervical spinal foramina was not performed because of increased mortality and morbidity. Electrophysiological studies included SSEP and MEP were done by a neurophysiologist (I.Y.).

SSEP measured evoked potentials from the brachial plexus distal to the somatosensory tracts centrally at the level of the central nervous system. SSEP evaluated somatosensory cervical spinal nerve integrity from the peripheral nerve to the central nervous system using cortical recording. MEP are neuroelectrical responses elicited from descending motor pathways. Intraoperatively, nasopharyngeal stimulating electrodes were placed and peripheral motor recording was done. Histopathological percent neuronal loss was determined using an intraoperative trichrome staining technique. Macroscopically abnormal spinal nerves were histopathologically stained with trichrome stain to obtain objective information on the amount of preserved myelinated fibers [6].

### Neuroradiological assessment

MR imaging and MR myelography were done in all patients. Details of the MRI protocol performed in a 1.5-T MR scanner are shown in Table 1. All patients were sedated with chloral hydrate orally (75 mg/kg) or pentobarbital (3–8 mg/kg) and midazolam (0.05–0.1 mg/kg) intravenously. Images were read by radiologists with advanced training in both pediatric imaging and neuroradiology. Radiologists were only aware of the side of the suspected brachial

**Table 1** MRI sequences for brachial plexus study

	Sequence					
	FSE T2-W 3D Coronal	FSE T2-W Sagittal	FSE T1-W Sagittal	FSE T2-W Axial	STIR Axial	SS FSE Coronal <sup>a</sup>
Echo time (ms)	100	120	10	120	10	1,000
Repetition time (ms)	1,000	3,500	400	3,500	2,500	8,000
FOV (cm)	22	20	20	22	22	20
Thickness/gap (mm)	1.5/0	3/0.3	3/0.3	4/0.4	4/0.4	30
No. of excitations	2	6	6	6	2	4
Time sequence	5–7 min	3 min 43 s	4 min 43 s	6 min 29 s	4 min 35 s	40 s

<sup>a</sup>MR myelogram

plexus injury. However, radiologists were blinded to the detailed clinical and electrophysiological examinations. Radiologists recorded for all studies the presence or absence of the following: (1) cord lesion; (2) pseudomeningocele; (3) injury of exiting nerve roots and (4) post-traumatic brachial plexus neuroma. A post-traumatic neuroma is a disorganized proliferation of regenerating axons at the proximal stump of a transected nerve [7]. It consists of nerve fascicles with Schwann cells, fibroblasts and axons with myelin [7].

## Results

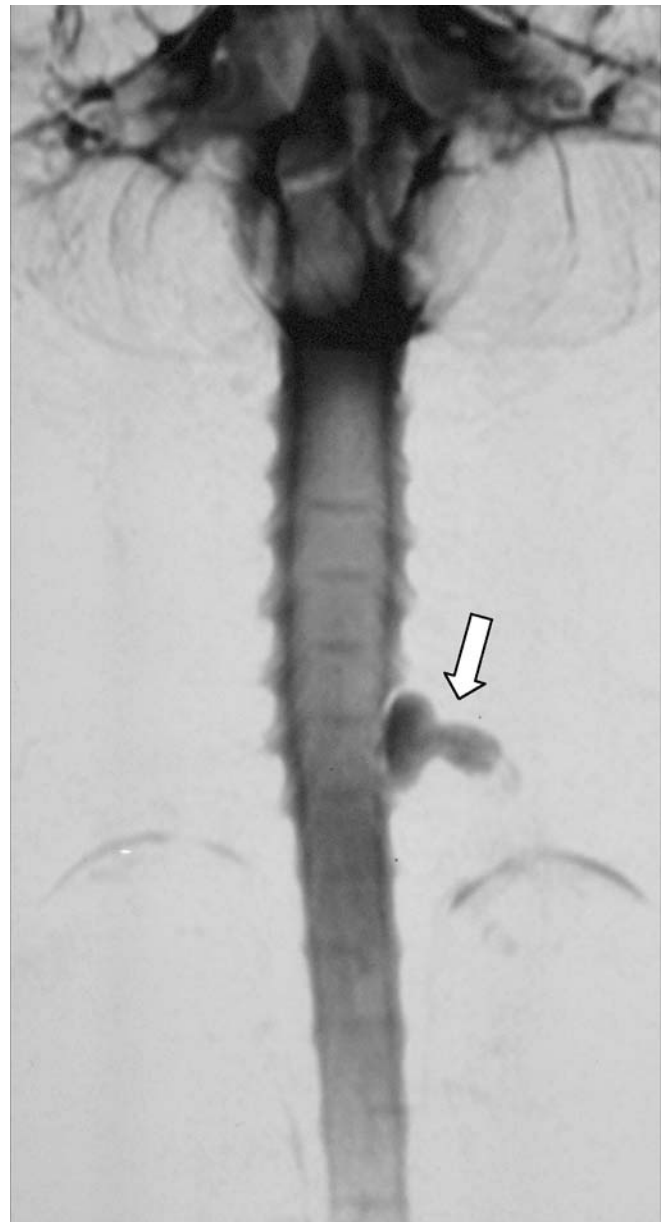
From June 2001 to March 2004, 31 children (mean age 7.3 months, standard deviation 1.6 months, range: 4.8–12.1 months; 19 male, 12 female) with perinatal brachial plexus injury who underwent surgical intervention were enrolled. All patients had surgery and underwent intraoperative (1) surgical evaluation and (2) electrophysiological studies, and (3) had biopsy proven histopathological neuronal loss. All 31 patients had SSEP and 10 of the patients had MEP performed. In the SSEP and MEP evaluations, a total of 70 and 26 nerve root levels were studied, respectively. All patients had preoperative cervical and brachial plexus MRI and MR myelography within 4 weeks of the surgical procedure. The MRI findings evaluated included cord lesion, exiting nerve root injury, pseudomeningocele (Fig. 1), and post-traumatic neuroma (Fig. 2). On MRI, these neuromas appeared as high-signal on T2-W and STIR images.

The standard of reference for post-traumatic neuroma was intraoperative surgical macroscopic evaluation. The sensitivity and specificity of the MRI finding of post-traumatic neuroma were 97% (30/31) and 100% (31/31), respectively, using the contralateral normal brachial plexus as the control. However, MRI could not determine the exact anatomical area in the brachial plexus (i.e. trunk or division) of the post-traumatic neuroma.

The sensitivity and specificity for MRI finding of pseudomeningocele in determining exiting nerve injury were 50% (1/2) and 100% (24/24), respectively, using MEP, and 44% (7/16) and 80% (43/54), respectively, using SSEP as the standard of reference. MRI in infants could not visualize well the exiting nerve roots to determine consistently the presence or absence of avulsion.

## Discussion

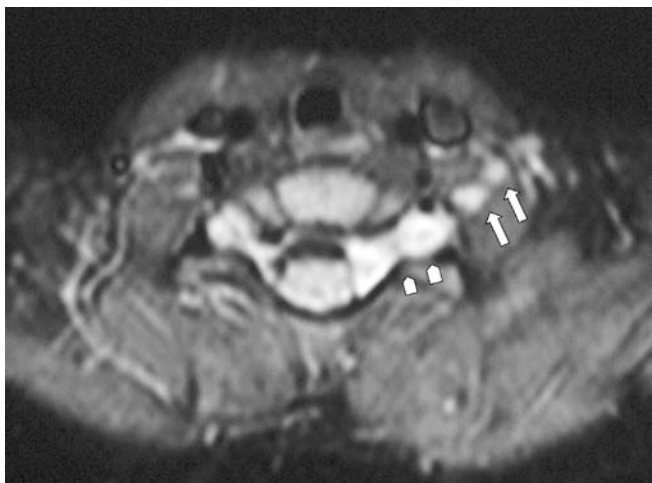
The ideal standard of reference for determining nerve root avulsion is exploratory laminectomy, a procedure during which the surgeon evaluates under direct visualization the integrity of the dorsal and ventral nerve roots [5]. However, few patients with suspected nerve root avulsions undergo this surgical procedure because it has morbidity and mortality risks [5]. Hence, non-invasive preoperative imaging and intraoperative electrophysiological studies are important in determining integrity of the dorsal and ventral



**Fig. 1** Single-shot FSE T2-W image using the MR myelographic technique shows a left C6-7 pseudomeningocele (arrow)

nerve roots for purposes of surgical reconstruction. Therefore, knowledge of the spinal nerve integrity is key information for neurosurgical management and planning [6]. These non-invasive studies are also important in determining pre- versus post-ganglionic nerve involvement.

Our study demonstrated that the MRI finding of pseudomeningocele had a low sensitivity but a high specificity for exiting nerve root avulsion. Therefore, the absence of a pseudomeningocele had a high correlation with intact exiting nerve roots. However, the presence of a pseudomeningocele cannot determine whether the nerve root is intact or avulsed. A post-traumatic neuroma is a disorganized proliferation of regenerating axons at the proximal stump of a transected nerve [7]. It consists of nerve fascicles with Schwann cells, fibroblasts and axons



**Fig. 2** Axial STIR image shows a left C6-7 pseudomeningocele extending into the foramen (*white arrowheads*) and post-traumatic neuroma (*white arrows*) between the anterior and middle scalene muscles

with myelin [7]. The MRI finding of post-traumatic neuroma with high signal on T2-W and STIR images had a high sensitivity and specificity in identifying the lesion but was not able to determine the exact anatomical areas of brachial plexus involvement (i.e. trunk or division).

In our population all patients were younger than 18 months. Direct evaluation of the exiting nerve roots was limited in our study population, even using thin 1.5-mm cuts and the MR myelographic technique. Therefore, direct exiting nerve root avulsion versus integrity could not be reliably evaluated. Studies in adults between the ages of 17 and 46 years have shown a sensitivity of 89%, a specificity of 95% and diagnostic accuracy of 92% in the evaluation of nerve root integrity [8]. A study by Doi et al. [2] in adults with a mean age of 27 years revealed a sensitivity and specificity of MRI for detecting the presence of root avulsion of 92.9% and 81.3%, respectively. However, other studies have shown lower diagnostic accuracy of MRI. The study by Ochi et al. [9] in 34 patients showed accuracies of MRI of 73% for C5 and 64% for C6. Blum et al. [10] consider that MR imaging can only identify approximately 70% of surgically proven root avulsions caused by traction injuries and suggest that MR is not the ideal standard of reference to determine root avulsion. No large series in children younger than 2 years have been published [11]. The limitation of evaluating optimally existing nerve roots in our infant population with MRI and MR myelography probably arises from the small size of these structures in this age group.

Other studies have indicated that CT myelography is the preferred imaging study. Carvalho et al. [4] reported a diagnostic accuracy of 85% for CT myelography and 52% for MRI in determining nerve root avulsion. The drawback of CT myelography is that it is an invasive procedure requiring intrathecal administration of contrast solution and ionizing radiation. CT myelography is challenging in newborns and infants because of their size and the need for sedation or general anesthesia. Walker et al. [3] found a

significant number of cervical myelograms inadequate to evaluate the nerve rootlets at all cervical levels in small infants under general anesthesia.

Our study had limitations. The standard of reference used for nerve root avulsion was MEP and SSEP, not direct surgical evaluation. MEP and SSEP have limitations in determining the degree of partial nerve injury. However, the ideal standard of direct surgical exploration of the exiting nerve roots has significant risks and morbidity. MEP and SSEP, therefore, were used in our study because they are less invasive reference standards. Not all patients with brachial plexus injury were enrolled. We only enrolled patients who underwent surgery in order to have the most robust standard of reference possible. Hence, the sensitivity and specificity of MRI described applies to this selected patient population and cannot be generalized to all patients with brachial plexus injury.

Future studies are clearly required. Direct visualization of the exiting nerve roots in infants is a technical limitation with current 1.5-T MR scanners. Prospective studies with higher magnetic fields (3 T and higher) with surface coils might provide a better signal-to-noise ratio to depict in more detail the anatomy and histopathology of the exiting nerve roots and different components of the brachial plexus. Functional MRI and diffusion tensor (tractography) imaging at a higher field might provide additional neurofunctional data for diagnosis and decision-making.

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## Conclusion

In children younger than 18 months with brachial plexus injury, the MRI finding of pseudomeningocele has a low sensitivity and a high specificity for nerve root avulsion. MRI and MR myelography cannot visualize well the exiting nerve roots to determine consistently the presence or absence of avulsion of nerve roots. The MRI finding of post-traumatic neuroma has a high sensitivity and specificity in determining the side of brachial plexus injury but cannot reveal the exact anatomical area (i.e. trunk or division) involved.

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