Fast spin–echo magnetic resonance imaging for radiological assessment of neonatal brachial plexus injury

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Neurosurgical management of birth-related brachial plexus palsy involves observing the patient for a period of several months. Operative intervention is usually undertaken at 3 to 6 months of age or more in infants who have shown little or no improvement in affected muscle groups. Ancillary tests such as electromyography and nerve conduction studies are occasionally useful. No radiological study has been consistently helpful in operative planning, except for contrast computerized tomography (CT) myelography, which requires general anesthesia in infants. This is because the infant’s size exceeds the functional resolution of the imaging modalities.

This report describes the use of a special sequence of magnetic resonance (MR) imaging entitled “fast spin echo” (FSE-MR). Unlike CT myelography, this technique provides high-speed noninvasive imaging that allows clinicians to evaluate preganglionic nerve root injuries without the use of general anesthesia and lumbar puncture. The utility of this technique is illustrated in three cases, two involving either infraclavicular exploration or a combination of infraclavicular and supraclavicular exposure based on FSE-MR findings. The FSE-MR imaging offers an excellent alternative to contrast CT myelography in evaluation of infants with birth-related brachial plexus injuries.

KEY WORDS • brachial plexus • spinal nerve root avulsion • birth injury • infant • magnetic resonance imaging

Magnetic resonance imaging (MRI) imaging techniques, which in adults demonstrate neural and vascular injuries to the brachial plexus and occasionally reveal evidence of cervical root avulsions, lack the resolution to be useful in the small structures of an infant’s body.1,7,9,15,21,30,32,33 Computerized tomography (CT) myelography is useful but requires an invasive procedure in an anesthetized infant. The findings of CT myelography show good correlation with intraoperative evoked responses;17,22,26,27 however, what is needed is a noninvasive modality that does not require general anesthesia to reveal anatomical lesions and aids in planning the surgical repair of these injuries.

Fast spin–echo MR (FSE-MR) imaging evaluates brachial plexus in infants by providing high-speed noninvasive imaging, with short imaging times that obviate the need for general anesthesia and lumbar puncture. The utility of this technique is illustrated in three cases, two involving either infraclavicular exploration or a combination of infraclavicular and supraclavicular exposure based on FSE-MR findings. The FSE-MR imaging offers an excellent alternative to contrast CT myelography in evaluation of infants with birth-related brachial plexus injuries.

Clinical Material and Methods

Fast Spin–Echo Magnetic Resonance Techniques

Magnetic resonance studies were performed on a 1.5-tesla Magnetom (Siemens, Erlangen, Germany). A quadrature knee coil was used for imaging all patients. A 180-mm field of view, with a 192 × 256 matrix, was used for all planes. Images were obtained in T2-weighted coronal, sagittal, and axial planes. Images in the sagittal plane were obtained using a repetition time (TR) of 6000 to 6748 msec and an echo time (TE) of 90 msec. A series or “train” of 16 echoes was used for all acquisitions.
Slice thickness was 3 mm in all planes. The time to perform a single acquisition was 1 minute and 30 seconds and for three acquisitions, 4 minutes, 30 seconds. For axial images, a TR of 6000 to 8000 msec was used with a TE of 90 msec. Axial acquisition times were 1 minute and 46 seconds for single and 5 minutes and 18 seconds for three acquisitions. Images were obtained with a single acquisition in each plane and, when possible, followed by three acquisitions in the coronal and axial planes. Coronal views were reconstructed from stacked coronal acquisitions, the plane of section deriving from a sagittal scout view in a plane parallel to the cervical lordotic curve using commercially available software (Voxelman; Vital Images, Fairfax, IA).

The FSE-MR technique can generate images in much less time than conventional spin echo. The MR images are obtained by applying selected radiofrequency pulses to tissues, which return radiofrequency signals that are used to generate the information to fill a matrix (in a typical illustration, 192 lines by 256 rows) and create an image. With FSE-MR techniques, four, eight, or 16 lines in a matrix may be filled for each TR, rather than a single line from each TR of conventional spin echo. This is possible because multiple excitations (four, eight, or 16) for each TR are used, with direct corresponding reduction in imaging time. This saving in time may be used to increase the size of the matrix (to improve resolution) or to increase the number of acquisitions (to improve signal-to-noise, with resulting improvement in image quality). The advantages of FSE-MR imaging are high intrinsic contrast and high signal-to-noise; these are used to obtain images with high resolution and contrast in much less time than is possible with conventional spin–echo techniques.

**Illustrative Cases**

**Case 1**

This male infant was born at 34 weeks of gestation, weighing 4 lb, 6 oz. Labor and delivery were complicated by fetal distress and breech presentation. Examination. At birth the infant had flaccid paralysis of the left upper extremity, which subsequently improved to no movement in the deltoid, biceps, triceps, and wrist extension; his wrist flexion was 2/5 and finger flexion was 4/5. In addition, he had a paralyzed left hemidiaphragm and episodes of bradycardia. Electromyographic and nerve conduction velocity studies showed denervation in the proximal left upper limb muscles, including the rhomboid, latissimus dorsi, pectoralis major, deltoid, biceps, and triceps, with no motor unit potentials in the deltoid, rhomboid, and latissimus dorsi, and markedly decreased motor unit potentials in the triceps, upper pectoral major, and biceps. These findings were consistent with left upper brachial plexus lesion with severe denervation of muscles and C-5, C-6, and C-7 segmental innervation. Preoperative somatosensory evoked potentials showed evidence of peripheral nerve responses to ulnar, musculocutaneous, and median nerve stimulation, but no cervical responses for the musculocutaneous and median nerves. These findings suggested that localization of the lesion was very proximal, potentially at the root level.

An MR examination using the FSE technique (Fig. 1) clearly delineated pseudomeningoceles at the left C-4, C-5, C-6, and C-7 root levels, and also at the right C-5 root. Possible nerve root avulsion is not clearly delineated with this technique. Further MR study revealed left glenoid fossa flattening and an effusion of the left shoulder joint, consistent with disuse and joint laxity.

Operation. After a 5-month period of close clinical observation, as well as preoperative FSE-MR imaging and electrophysiological studies, a decision was made to perform infraclavicular nerve repair rather than supraclavicular exposure of the brachial plexus. The left phrenic nerve was neurotized using the seventh and eighth intercostal nerves and in particular an eighth intercostal nerve motor branch to the rectus abdominis muscle. Direct electrical stimulation of the seventh and eighth intercostal nerves demonstrated brisk, strong contraction of the rectus abdominis. The left hemidiaphragm underwent reeving through a left anterolateral thoracotomy at the fifth intercostal space, and the phrenic nerve was then neurotized.

**Fig. 1. Case 1. Preoperative fast spin–echo magnetic resonance images in a 5-month-old boy with left brachial plexus injury. He showed no movement in the proximal left upper extremity and weak wrist flexion and finger movement distally. Left: Reconstructed coronal T₂-weighted image from coronal single acquisition. Note pseudomeningoceles at left C-4, C-5, C-6, C-7, and right C-5 root levels (arrows). Right: Direct axial T₂-weighted image, single acquisition. Note pseudomeningoele of the left C-6 root (arrows), left shoulder effusion (small arrow).**
Direct stimulation of the median, ulnar, and radial nerves showed normal, appropriate muscle contractions. Direct stimulation of the very proximal musculocutaneous nerve yielded no contractions. The lateral antebrachial cutaneous nerve of the musculocutaneous nerve was transected and direct neurotization of the biceps muscles was performed. Three medial pectoral nerve branches were identified proximally in the wound at their exit from the medial cord and were transected close to their pectoralis muscle attachment. The proximal musculocutaneous nerve was transected distal to the branch to the coracobrachialis (where there was evidence of a second injury) and was readily neurotized by the adjacent medial pectoral branches. In this procedure, only the most distal portion of the brachial plexus was explored to provide functional reinnervation where it was most needed, to the left biceps brachialis muscle.

Postoperative Course. Although there was no improvement in proximal upper-extremity strength and hemidiaphragm function soon after the operation, there was continued improvement in finger and hand movement (to 4+/5). At 8 months postoperation a chest radiograph and fluoroscopy demonstrated that the patient had functional reinnervation of the left hemidiaphragm. There was improvement of proximal upper-extremity strength, with biceps and triceps improving to 2/5 (from 0/5); the deltoid muscle remained at 0/5, but did not show progressive atrophy.

Case 2

This female infant, weighing 9 lb and 4 oz, was delivered vaginally in a vertex presentation at 39 weeks of gestation after a 22-hour labor. Midforceps and suction extraction were used.

Examination. At birth she had ecchymosis over the left shoulder, flaccid paralysis with areflexia of the entire left upper extremity, and a left Horner’s syndrome suggestive of a proximal root avulsion injury to the lower cervical/upper thoracic spinal cord. Immediately prior to surgery, she showed no movement in the left upper extremity except for new 2/5 deltoid function.

The electromyographic and nerve conduction velocity studies revealed severe denervation in all proximal and distal muscles of the left upper extremity in association with loss of median and ulnar sensory neuron action potentials and compound muscle action potentials, suggesting the presence of severe postganglionic lesions. No motor unit potentials were observed in any of the left upper-extremity muscles.

An MR imaging examination was performed on her 6th day of life, using the FSE technique. Pseudomeningoceles were demonstrated at the left C-7 and C-8 nerve roots, suggesting a possible nerve root avulsion at these levels (Fig. 2). Infiltration of the soft tissues within the left brachial plexus proper was consistent with edema and hemorrhage and suggestive of brachial plexus injury. The MR study also showed soft-tissue swelling in the deep muscle planes about the left shoulder, consistent with recent trauma.

Operation. At 3.5 months of age the patient underwent a combined infraclavicular and supraclavicular exposure of the brachial plexus and brachial nerves, which was performed based on monthly physical examinations and on electrophysiological and FSE-MR findings of pseudomeningoceles and possible avulsions of the C-7 and C-8 nerve roots. Extensive injury of the entire brachial plexus proper was noted, and a second injury was seen in the musculocutaneous and axillary nerves. After intraoperative electrophysiological recordings and stimulation showed evidence of brisk muscle activity in the deltoid and biceps muscles when stimulating across the C-5 and
C-6 nerve root–associated neuromas, this child underwent neurolysis of the upper brachial plexus.23 Nerve stimulation of the lateral pectoral nerves showed brisk response in the pectoralis major. Motor innervation to muscles supplied via the medial cord was provided by neurotization of the medial cord using motor branches of the lateral pectoral nerve.

At surgery, the transected ends of the lateral pectoral nerves showed a viable nerve at the stump. This, combined with the brisk response of the pectoralis major to lateral pectoral nerve stimulation and no motor response to lower plexus stimulation, suggested the use of the lateral pectoral nerve in medial cord neurotization. Sensory innervation was supplied to the lateral division of the median nerve by sensory neurotization provided by sensory branches of the upper intercostal nerves. The medial antebrachial cutaneous nerve underwent sensory neurotization by the intercostobrachial nerve. These neurotizations were performed to provide some sensory and motor innervation to nerves previously supplied by the avulsed C-7 and C-8 nerve roots.

Postoperative Course. At follow-up examination 4 months after surgery, the child had improved left deltoid strength to 2/5, biceps to 1/5; the triceps and distal left upper extremity remained 0/5. Biceps, triceps, and brachioradialis reflexes were all 1+.

Case 3

This male infant, weighing 12 lb, was born at 37 weeks of gestation. The pregnancy was complicated by maternal gestational diabetes mellitus. The child was born in a vertex presentation but required vacuum assistance because of macrosomia. His immediate postnatal course was complicated by cardiac arrest requiring cardiopulmonary resuscitation.

Examination. The boy displayed 0/5 left deltoid strength, 2/5 left triceps, 4/5 left biceps, 4/5 supination, normal pronation, 4/5 wrist extension, and normal grasp strength. Deep tendon reflexes were absent in the left upper extremity. He had no Horner’s syndrome, and there were no external signs of left shoulder injury. A chest x-ray film revealed no signs of clavicular fracture and normal position of the left hemidiaphragm. Electromyographic and nerve conduction velocity studies were not obtained.

Results of FSE-MR imaging on the 7th day of life were normal, with no pseudomeningoceles or signs of significant root injury (Fig. 3). Early imaging in this patient was performed to evaluate for its possible benefit soon after birth injury.

Management. In view of the initial clinical examination and normal FSE-MR findings, conservative management was undertaken, with monthly evaluation for neurological improvement. The infant regained symmetrical and full motor strength of the upper extremities in 6 months.

Discussion

Birth-related brachial plexus injury initially was thought to be secondary to external compression of the brachial plexus. Sever6 was the first to suggest that excessive lateral neck flexion at delivery could cause a stretch injury. In many series, rupture injuries are more commonly seen in the upper roots of the brachial plexus, producing Erb’s palsy. Avulsions appear to be more common in the lower roots, causing a clinical presentation of Klumpke’s paralysis.23 Factors that appear to increase risk for brachial plexus injury in infants include prolonged labor, shoulder dystocia, increased birth weight, and multiparity. How to decide which cases require surgery has not been clearly defined. These children present with an Erb’s, complete brachial plexus palsy, or Klumpke’s paralysis, but this initial presentation does not allow the clinician to predict the final neurological outcome. Conservative practice involves frequent neurological evaluation for improvement or lack thereof. Wickstrom9 reported that 60% of birth-related brachial plexus injuries do not recover to good functional status in the upper extremity. Gjørup12 found that 70% had no functional recovery although 30% had some recovery. Wyeth and Sharpe5 recommended surgery in infants if no recovery was demonstrated by 3 months of age, as did Metaizeau, et al.,24 and Gilbert and Tassin.11 Bennet and Harrold1 used a 5-month cutoff as their time period for evaluation of recovery. Laurent and colleagues25 used a 4-month cutoff in their evaluative criteria. It appears that if surgery is planned before the infant is 6 months of age, electromyographic and nerve conduction velocity studies and FSE-MR imaging are necessary because not enough time would have elapsed for adequate regeneration to be clinically evaluated. Performing surgery on an infant younger than 3 months of age is not recommended; however, surgery later than 1 year is also not...
favored because of worse outcomes resulting from muscle degeneration.

The lack of preoperative studies is one reason for the emphasis on clinical examination to determine the timing of surgical exploration. Although electromyogram, nerve conduction velocity studies, and somatosensory evoked potentials have been used, these evaluations do not help predict neurological improvement; sensory evoked potentials do not distinguish between incomplete avulsions and intact roots. Myelography with CT allows determination of the presence of nerve root avulsions by demonstrating traumatic pseudomeningoceles. An MR examination is more effective than cervical myelography and CT in demonstrating complete cervical avulsions, but thus far is applicable only to adolescents and adults.

Experimental MR microscopy enables visualization of the avulsed roots separated from the spinal cord, but the small bore of the current high-field magnets and the long acquisition time make this technique unsuitable for clinical application. Conventional MR techniques in adults may demonstrate large traumatic pseudomeningoceles but cannot delineate the root avulsion or show changes in the spinal cord. A report by Blum, et al., stated that MR imaging only identified approximately 70% of surgically proven root avulsions caused by traction injuries and suggests that neither MR nor CT myelography is the gold standard for determining whether there has been a root avulsion.

Although MR imaging of the brachial plexus proper can be performed in adults, the evaluation of this problem in newborns and infants is particularly difficult because of the patient’s small size. No MR technique described and published to date has high enough spatial resolution to evaluate the individual trunks, divisions, cords, and nerves of the brachial plexus proper.

In this report we present the FSE-MR technique that visualizes pseudomeningoceles, indicating the probability of associated nerve root avulsions. The FSE-MR technique offers high resolution, excellent intrinsic tissue contrast, and shorter acquisition time than other MR imaging sequences. To obtain these advantages using any other imaging method would require general anesthesia. We found that bottle sedation/feeding or mild sedation usually allowed satisfactory data acquisition with this technique. In addition, the MR data could be reconstructed in a plane parallel to the cervical curve, enabling the viewer to look at the entire cervical and upper thoracic cord at equivalent depths. This was easier to assess visually and eliminated missing anatomical details caused by the cord traversing in and out of the section of imaging.

In our patients, FSE-MR imaging was of considerable value in operative planning because of its ability to demonstrate pseudomeningoceles. In Case 1, the study clearly delineated pseudomeningoceles and/or traumatic neuroomas at C-4, C-5, C-6, and C-7. The anatomical detail provided by this FSE-MR study led us to choose infraclavicular exploration of the brachial plexus, a more individualized operative intervention for the patient. Neurorotation of the left phrenic nerve using the intercostal nerves provided innervation to the left hemidiaphragm and resulted in functional recovery 8 months after surgery.

Neurorotation of the left musculocutaneous nerve using the medial pectoral nerve provided innervation to the left biceps and brachialis muscles, which functionally enabled elbow flexion and some shoulder flexion.

In Case 2, the Horner’s syndrome present immediately after birth suggested an avulsion of the C-8 and/or T-1 nerve roots, and a flaccid left upper extremity suggested additional injury to the rest of brachial plexus. An FSE-MR study demonstrated evidence of an avulsion of C-7 and C-8 nerve roots and additional injury to the rest of the brachial plexus. Armed with this information, we decided to operate when the child was 3.5 months of age. Early operation was desirable to give the best functional outcome by providing the maximum amount of time for reinnervation of distal musculature. In this infant, nerve repairs were performed in combination with neurolysis to provide motor and sensory innervation to the distal upper extremity from less critical innervations (lateral pectoral nerves and the intercostobrachial nerves).

Case 3 shows the common situation of an infant presenting with flaccid upper extremity but with an FSE-MR study revealing no evidence of nerve root avulsion or pseudomeningocele formation. This child was managed with conservative therapy, and had full, symmetrical motor recovery without undergoing operative treatment.

Conclusions

An FSE-MR study appears useful in evaluation of neonatal brachial plexus injury because it clearly delineates pseudomeningoceles. Unfortunately, MR imaging, including the FSE technique presented here, does not visualize all components of the brachial plexus outside the spinal canal in infants. Further refinement of imaging techniques is needed to evaluate these infants more precisely so that an informed decision can be made on operative treatment at the earliest possible time.

References


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