Fetal Magnetic Resonance Imaging Enhances Detection of Spinal Cord Anomalies in Patients With Sonographically Detected Bony Anomalies of the Spine

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Objective. Although fetal magnetic resonance imaging (MRI) is being increasingly used to evaluate sonographically suspected abnormalities, its utility in the evaluation of the spinal canal is not well studied. Because it is not susceptible to the limitations of fetal position, oligohydramnios, and shadowing from bony structures, we hypothesize that fetal MRI is better suited to assess the contents of the spinal canal compared with prenatal sonography. The purpose of this investigation was to determine whether fetal MRI could detect spinal abnormalities in cases in which they had not been originally suspected on prenatal sonography.

Methods. Fetal spine MR images were retrospectively reviewed over a 42-month period. Corresponding sonographic images were then rereviewed to determine whether there were findings in retrospect that might have suggested the cord abnormalities. Cases of myelomeningocele were counted as a spinal cord abnormality only if fetal MRI showed a cord anomaly other than the myelomeningocele.

Results. Of 33 cases referred for bony anomalies of the spine, fetal MRI showed additional abnormalities involving the spinal cord in 3 patients. These included diastematomyelia in 2 cases and segmental spinal dysgenesis in the third case. One case of diastematomyelia occurred in association with a lumbosacral myelomeningocele. The spinal cord anomalies were not visible on any of the prenatal sonograms, even in retrospect.

Conclusions. Additional spinal cord anomalies were detected in 10% of cases reviewed. Fetal MRI can be useful in assessing the spinal cord in fetuses with bony spinal anomalies. Our findings suggest that fetuses with sonographically diagnosed bony abnormalities of the spine may benefit from further evaluation with fetal MRI.

Key words: fetal magnetic resonance imaging; fetal sonography; spinal cord anomalies; vertebral body anomalies.

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Abbreviations
MMC, myelomeningocele; MRI, magnetic resonance imaging; SCM, split cord malformation; SSFSE, single-shot fast spin echo

With the advent of ultrafast fetal magnetic resonance imaging (MRI), it has become possible to image the developing fetus safely and without sedation. Fetal MRI has been shown to be beneficial in providing additional anatomic information in cases of suspected fetal abnormalities seen on prenatal sonography.1-6 Congenital anomalies of the central nervous system such as partial or complete agenesis of the corpus callosum, Dandy-Walker malformation, periventricular nodular heterotopia, and other cortical malformations are diagnosed more reliably on the basis of fetal MRI compared with prenatal sonography.1-8
The benefit of fetal MRI in assessing spinal anomalies is less well documented. Myelo- meningoceles (MMCs) seen on prenatal sonography are usually confirmed on fetal MRI, and the accuracy of assigning a lesion level is similar for sonography and MRI. Others have shown that sonography may be superior for skeletal deformities compared with MRI. Indeed, sonographic evaluation of the spine can be limited by oligohydramnios, maternal obesity, and fetal position. Shadowing from the bony structures can also preclude a complete evaluation of the spinal cord and arachnoid sac. Because fetal MRI is not susceptible to these same limitations, it seems better suited to evaluate the contents of the bony spinal canal. We therefore chose to retrospectively determine the frequency of spinal cord anomalies in patients referred for sonographically detected spinal column anomalies and to determine whether these anomalies were detectable, in retrospect, on the sonograms. We hypothesized that the majority of spinal cord anomalies detected on fetal MRI are sonographically occult.

Materials and Methods

We retrospectively identified cases with suspected bony abnormalities on prenatal sonography that were referred for fetal MRI of the spine from December 1998 to June 2002. Institutional Review Board approval was obtained before initiation of this study. We included cases of bony anomalies related to an MMC defect. Fetal MR images were retrospectively reviewed by a pediatric neuroradiologist (O.A.G.) who was aware that all cases had a suspected bony abnormality but was blinded to the clinical history and initial imaging results. Cases with spinal cord anomalies on fetal MRI were identified, and the sonographic images of these cases were then retrospectively reviewed by a sonologist (R.B.G.) with expertise in fetal sonography. Cases of bony spina bifida in association with MMC were not classified as a spinal cord anomaly unless additional anomalies, such as diastematomyelia, were seen. Gestational age was based on sonographically estimated gestational age.

All fetal MRI examinations were performed with a 1.5-T magnet (GE Healthcare, Milwaukee, WI) and a torso phased array coil. Single-shot fast spin echo (SSFSE) T2-weighted 2- to 4-mm
Images were acquired in the axial, sagittal, and coronal planes with respect to the fetus, with the exception of 1 patient in whom axial images were not obtained. The field of view was 24 to 28 cm depending on gestational age. Fetal sonographic examinations at our institution were performed with Acuson Sequoia sonographic equipment (Siemens Medical Solutions, Mountain View, CA) and sector or curved array multifrequency (4- to 8-MHz) transducers. Multiple sonographic images of the fetus were acquired, including sagittal and axial images in all fetuses.

Results

Thirty-three patients were referred for fetal MRI of the spine for sonographically detected spinal column abnormalities from December 1998 to June 2002. Twenty-eight of the 33 patients were referred for MRI evaluation of MMC diagnosed on the basis of prenatal sonography. The mean gestational age at the time of the MRI was 22 weeks 2 days (range, 18 weeks 0 days–34 weeks 2 days). Of the 33 cases, 3 had poor-quality MR images and were judged to be insufficient to assess for spinal cord anomalies. In 3 (10%) of the

Figure 1. (continued) C–F, Progressing from rostral to caudal in the axial plane, a single spinal cord (C, arrow) changes into a duplication (D, arrow) and 2 separate hemicords (E, arrow) until they rejoin to a single cord at the thoracic level (F, arrow). A large congenital diaphragmatic hernia is also shown (C, arrowhead).
remaining 30 patients, sonographically undetected anomalies of the spinal cord were identified by fetal MRI. The spinal cord anomalies included diastematomyelia in 2 cases and segmental spinal dysgenesis in the third case. The spinal cord anomalies were not visible on the prenatal sonograms, even in retrospect. The mean interval between prenatal sonography and fetal MRI was 0 days (range, 0–1 days). Postnatal imaging was available in 1 case; the other 2 remaining cases were not followed postnatally at our institution.

Figure 2. A–C. Sonograms of a fetus at 24 weeks 6 days showing no appreciable bony defect in the cervical or thoracic spine in the coronal plane (A) but showing an L1-to-S1 MMC in the coronal plane (B, arrow) and in the axial plane (C, arrow). D. Coronal SSFSE T2-weighted MR image obtained on the same day showing splitting of the upper and mid thoracic cord (arrow), consistent with a diastematomyelia. E. Axial SSFSE T2-weighted image confirming the presence of 2 hemicords in the thoracic spine (arrow).
One case of diastematomyelia occurred in a fetus with multiple segmentation anomalies of the cervical spine detected on prenatal sonography at 25 weeks 2 days (Figure 1). In addition to identifying abnormal bony alignment in the cervical spine, fetal MRI identified a single spinal cord that transitioned into 2 separate hemicords and subsequently joined to a single cord at the thoracic level (Figure 1, A–F). In the second case of diastematomyelia, prenatal sonography at 24 weeks 6 days showed an MMC defect from L1 to S1 without other morphologic abnormalities (Figure 2, A–C). Fetal MRI performed on the same day confirmed the MMC defect but also identified 2 spinal hemicords in the upper and mid thoracic spine, consistent with a diastematomyelia (Figure 2, D and E).

Sonographically occult segmental spinal dysgenesis was diagnosed in the third case (Figure 3). A prenatal sonogram at 23 weeks 2 days showed multiple bony abnormalities of the distal lumbar spine without any abnormalities within the bony spinal canal (Figure 3, A and B). Fetal MRI identified additional findings of abnormal blunt termination of the spinal cord at the level of the diaphragm with neural tissue in the distal lumbo-sacral canal, consistent with segmental spinal dysgenesis (Figure 3C). Fetal MRI findings were confirmed on postnatal imaging (Figure 3D).

**Discussion**

Because it is not susceptible to the same limitations as sonography and can now be performed safely and rapidly without maternal sedation, fetal MRI is being increasingly used for evaluation of suspected fetal anomalies.3–8,11–13 Fetal MRI is usually performed with the use of ultra-fast T2-weighted sequences after 20 weeks' gestation; imaging of younger fetuses is limited by increased fetal motion and small size of the regions being assessed.6 Earlier studies have shown that fetal MRI can result in change of diagnosis and change in management in nearly half of cases.1,3 Additional studies have also shown that most malformations of cerebral cortical development detected on fetal MRI are sonographically occult.4,14,15

Although there have been numerous studies on fetal MRI in the evaluation of sonographically suspected brain abnormalities, the utility of fetal MRI in the evaluation of the spine is less well studied. We found that fetal MRI identified additional spinal cord anomalies in 10% of cases referred for evaluation of sonographically detected bony spine anomalies. In particular, fetal MRI showed sonographically occult diastematomyelia and segmental spinal dysgenesis.

Diastematomyelia, also known as a split cord malformation (SCM), refers to a spectrum of spinal cord separation, ranging from a partially separated spinal cord in a single dural sac to a duplicated spinal cord with 2 dural sacs. According to a recent classification by Pang et al.14,15 type I SCM consists of 2 hemicords each contained in a separate dural sleeve and separated by an osseous or cartilaginous septum. Patients have a hairy tuft along the back, vertebral anomalies, including hemivertebrae, butterfly vertebrae, and posterior spina bifida, scoliosis, and a tethered cord. Type II SCM consists of a single dural sac containing both hemicords, although a fibrous septum can be seen between the hemicords. Vertebral anomalies are milder compared with type I SCM. During embryologic development, the 2 paramedian notochordal processes fail to integrate and remain separated by intervening primitive streak cells. Each heminotochord induces a separate neural plate. Primitive streak cells can either develop toward bone or cartilage and can result in a bony spur that keeps the spinal cords separated, resulting in a type I SCM, or become absorbed, resulting in a type II SCM.16,17 Sonography can identify anomalies of spinal alignment such as hemivertebrae, vertebral fusion, a thickened spinal canal, and a bony spur as an echoic mass.18 Split cord malformations may be associated with other dysraphisms, segmental anomalies, or visceral malformations.19 An isolated SCM has a favorable prognosis,19 and surgery is indicated for symptomatic lesions.15

Segmental spinal dysgenesis is a rare congenital spinal anomaly20 characterized by segmental dysgenesis or agenesis of the lumbar or thoracolumbar spine.16,17 Embryologically, abnormal notochordal development during gastrulation results in abnormal development of the prospective neuroectoderm and spinal cord. At the involved level, the spinal cord is thinned or even absent, and the overlying vertebral bodies are abnormally formed. The lower spinal segment is thickened and usually low lying. Radiographically, segmental anomalies are seen to involve vertebral bodies, the spinal cord, and nerve roots spanning the thoracic, lumbar, or sacral spine.
Figure 3. A and B, Sonograms of a fetus at 23 weeks 2 days with evidence of lumbar spine bony segmentation anomalies (arrows). C and D, Sagittal SSFSE T2-weighted fetal MR images obtained on the same day showing early termination of the spinal cord (C, arrow) with additional neural tissue in the sacral canal (D, arrow), consistent with segmental spinal dysgenesis (continued).
Figure 3. (continued) E, and F, Sagittal fast spin-echo T2-weighted postnatal MR images at approximately 5 months of age confirming the early termination of the spinal cord (E, arrow) as well as neural tissue within the distal spinal canal (F, arrow).
Vertebral anomalies can be seen on sonography. Clinically, patients have congenital paraplegia or paraparesis and lower extremity deformities. The extent of the neurologic defect depends on how functional the remaining spinal cord is. Overall prognosis depends on the extent of underlying spinal cord injury and associated malformations such as a neurogenic bladder and renal abnormalities.

Prenatal knowledge of spinal cord anomalies is important for prenatal counseling as well as surgical treatment. Knowledge of a diastematomyelia in addition to an MMC aids the pediatric neurosurgeon in the surgical planning. Because segmental spinal dysgenesis can be associated with substantial urodynamic dysfunction, in addition to a lower extremity neurologic deficit, accurate prenatal identification of this anomaly may be useful for prenatal counseling of the parents.

In our study, it is interesting to note that the spinal cord anomalies were at the same level as the bony anomaly in 2 of the 3 cases. We have found in our clinical experience that bony anomalies are easier to identify and characterize with sonography compared with fetal MRI. This is primarily because of the limited sequences available for use in fetal MRI and because of fetal motion. Although computed tomography can also be used to evaluate bony structures, it is not performed during pregnancy because of risks of radiation exposure to the fetus. Sonography, therefore, is best suited for the evaluation of bony anomalies in the fetus and can help guide MRI evaluation of the spinal canal.

It is also interesting to note that an associated diastematomyelia was identified in only 1 of 25 cases of MMC. This is somewhat lower than the reported 6% to 36% prevalence of diastematomyelia in the setting of MMC. This discrepancy may reflect a difference in the patient population or a lack of sensitivity of fetal spine MRI. Comparison with postnatal MRI is needed to clarify the reason for the difference.

Our results support the findings of others who have reported that spinal cord anomalies, such as diastematomyelia, a tethered cord, and caudal regression, can be identified by fetal MRI. In a recent review of 3 cases of diastematomyelia, Sonigo-Cohen et al were able to detect a split spinal cord on prenatal sonography, although fetal MRI was useful in further characterizing the abnormality.

Blaicher et al reported better diagnostic accuracy using sonography in comparison with fetal MRI in 10 of 14 patients with fetal skeletal deformities. In 4 patients with spina bifida, fetal MRI provided useful information for future neurosurgical planning. Furthermore, they found that fetal MRI was beneficial in parental counseling in 5 patients but did not affect perinatal management. This study supports our findings that in select patients, fetal MRI can aid in parental counseling.

In our 33 fetal patients with bony spinal defects diagnosed on the basis of prenatal sonography, examination with fetal MRI was beneficial to 3 patients by identifying additional abnormalities involving the spinal canal and spinal cord. Prenatal diagnosis of associated spinal cord defects may aid in prenatal counseling of parents and could direct further treatment of the fetus. We suggest that fetuses with sonographically diagnosed bony abnormalities of the spine may benefit from further evaluation with fetal MRI, especially if fetal surgery for spinal anomalies proves beneficial in the future.

References


