Neural tube defects are the second most common congenital anomaly, after cardiac malformations. Currently, in the United States, the average prevalence is one in 1000 live births. A geographic pattern has been observed, with higher prevalence in the United Kingdom and a lower rate in Japan. Similarly, the North American east coast has a higher prevalence than the west coast. Caucasians are more affected than blacks and Asians. Multiple risk factors have been observed. Anencephaly and spinal dysraphism constitute the bulk of the neural tube defects. Eighty percent of the cases of spinal dysraphism are manifested as open defects, meaning that they are not skin-covered. For this reason, they are...
amenable to prenatal detection with maternal alpha-fetoprotein blood serum screening. This is not the case in the remaining 20%, which occur in the form of closed defects (skin-covered). Ninety percent of the open defects are myelomeningoceles. These are posterior midline herniations of a low-ending and malformed spinal cord and nerve roots, within an expansion of the subarachnoid space through a defect in the vertebral laminae. Many times scoliosis is present concurrently. At present, ultrasonography has a very high sensitivity and specificity in the prenatal detection of these defects and their associated cranial Arnold-Chiari II malformation.

At birth, and for survival, the spinal defect needs to be closed. For that, the abnormal neural placode is dissected away from the surrounding tissues and reinserted into the canal. The dura is freed and is closed to guard against fluid leak. The skin is mobilized and closed on the surface. Sometimes additional vertebral resection is required. In addition, the associated cerebral ventriculomegaly requires a ventriculoperitoneal shunt for drainage of cerebrospinal fluid in 90% of patients. Fifteen percent of the patients will die by the age of 10 years, mostly owing to hindbrain dysfunction, which may result in sudden death as well as pain at the base of the skull and neck, nystagmus, weakness, hypotonia and spasticity of the upper extremities. All patients have urinary dysfunction and variable degrees of motor deficit of the lower limbs. Ninety percent of the patients also have kyphoscoliosis. Seventy-three percent of affected persons have an IQ greater than 80, but 50% of them have learning disabilities. With this background, the myelomeningocele patients are clinically followed for detection of retethering of the cord. This clinical syndrome is manifested by progression of the scoliosis (50%), motor loss (51%), spasticity (40%), and back pain (4%). In a series of 60 patients with myelomeningocele repair, 15% had clinical findings of retethering of the cord. In addition to the described findings, Tamaki and coworkers report leg pain, foot deformity, lower limb numbness and atrophy, and bowel dysfunction.

Since the advent of MR imaging, this modality has been the procedure of choice for the imaging of patients with congenital spinal abnormalities. Although the resulting images are optimal, MR imaging has been unable to allow prediction of the clinical deterioration of cord retethering. In addition, MR imaging has some drawbacks because of its relatively high cost, requirement for sedation and monitoring in young children, and the need to perform the study with the patient in the supine position with the cord dropping dorsally against the posterior wall of the spinal canal. This position makes it difficult to evaluate for cord adhesions, which are mostly dorsal. In this context, we attempted to evaluate the value of ultrasonography in the same kind of spinal studies and to compare it with MR imaging.

**METHODS**

The purpose of the study was to test the feasibility of using ultrasonography of the spine in the follow-up evaluation of patients who underwent closure of a myelomeningocele at birth. Prospectively, we collected our data and compared the ultrasonographic findings to those of MR imaging. The individual films were reviewed. We evaluated the quality of the studies, the location of the distal end of the cord, measurements of the cord and dural sac in the axial plane, position of the cord in the canal, presence or absence of cord adhesions, cord pulsation at the lower thoracic and lower lumbar regions, hydromyelia-syrinx, nerve root thickening of the cauda equina, mass in the dural sac, and diastematomyelia.

From 1993 to 1997, we studied 101 patients. The patients were mostly under 6 years of age (range, 1 month to 34 years) (the last age in one patient only). On these patients we performed 165 ultrasonographic studies and correlated them with 127 MR imaging studies. The time interval between the sonographic and MR imaging examinations was mainly under 6 months, with a range from the same day to up to 3 years (the last interval in one patient only). The indication for the sonograms was suspected retethering of the cord from clinical or MR image findings. The sonographic examinations were performed using 128 XP/10 Acuson units (Acuson, Mountain View, CA) and an Ultramark 9-HDI ATL unit (Advanced Technology Laboratories, Bothell, WA). The transducers were mainly linear but occasionally sector array with a frequency of 5-7 MHz. The patients were examined with a maximum feasible flexion of the spine in the left lateral decubitus or sitting up (Fig. 1). The MR imaging studies were performed using a Signa 1.5 Tesla unit (General Electric Medical Systems, Milwaukee, WI) with standard sequences. Some of the MR imaging studies were performed outside our institution.

The ultrasonographic and MR imaging studies were interpreted separately by different radiologists with no information on the other studies. Sonographic studies were read by one reader.
(E.O.G.), and MR imaging studies were single read by two readers (V.P., M.W.A.). Pertinent data were entered on individual forms as per protocol.

The successful examinations were divided into good (adequate visualization of the structures of the canal), acceptable (limited visualization of the structures of the canal), and poor (insufficient information on the structures of the canal).

Agreement between ultrasonograms and MR images regarding location of the distal end of the cord (Fig. 2) was considered when the difference was within ± one vertebra.

Measurements of the cord and dural sac were obtained in the axial plane and as close to the mid-lumbar area as feasible (Fig. 3). For measurements of the cord in the axial plane, we allowed a standard deviation of ± 2 mm between ultrasonograms and MR images. As the dural sac is significantly

**Figure 1** Patient’s position for the examination. **A**, Lateral decubitus. **B**, Sitting up. Observe the flexion of the spine in both positions.

**Figure 2** Low-ending cord (large arrow) at the distal sacrum with distal adhesions (small arrows) in a 1 year old girl, sagittal plane. **A**, T1 weighted MR image. **B**, Ultrasonogram. S, Superior; A, anterior.
larger than the cord, we allowed a standard deviation in the measurements of ±5 mm.

The position of the distal cord in the spinal canal at the lumbosacral area was divided into dorsal, central, and ventral (Fig. 4).

We evaluated the pulsation of the cord with M-mode (Fig. 5) and subjectively. The findings, which were categorized as present or absent, were evaluated at two sites: at the low thoracic area, which we considered to represent free cord, and at the lumbosacral area immediately above the area of possible adhesions. We compared these findings with the presence or absence of adhesions.

RESULTS

The ultrasonographic examination had a failure rate of 20% (33 of 165). MR imaging had no failures. We defined a failed examination as one that did not allow visualization of the canal.

Of the successful examinations, we considered the sonographic examinations to be good in 86%, acceptable in 13%, and poor in 1%; for the MR imaging examinations 98% were good, 2% were acceptable, and none were poor.

The distal end of the spinal cord was located at the low lumbar or sacral levels in most cases. Sonographic and MR imaging findings were in agreement regarding this location in 82% of the studies.

On measurements of the cord we obtained agreement between the sonographic and MR imaging studies in 85% of the anteroposterior diameter measurements and 79% of the transverse measurements. On measurements of the dural sac we obtained matching results of sonography and MR imaging in 82% of the anteroposterior diameter measurements and 48% of the transverse measurements.

The cord position was dorsal in 58% of the ultrasonograms and 93% of the MR images, with a matching of 59%. The cord was central in 39% of the sonographic studies and 6% of the MR imaging studies, with matching findings in 3%. The cord was ventral in 2% of the ultrasonographic studies and 1% of the MR imaging studies, with no matching findings.

Cord adhesions were found at the lumbosacral area in the region of the closure of the myelomeningocele (Figs. 2, 4). Ultrasonography showed them in 62% of the studies and MR imaging in 11%, with matching findings between the two modalities in 42%.

Patients with cord adhesions were found to have absent pulsation at the lumbosacral area in 57% of the studies and at the low thoracic area in 35% of the studies. Patients without cord adhesions were found to have absent pulsation at the lumbosacral area in 20% of the studies and at the lower thoracic region in 7%.

Figure 3 Sonographic measurements (calipers) in axial sections at the lumbar level in a 3 year old girl. A, Cord. B, Dural sac.
Hydromyelia or syrinx was found by ultrasonography in 23% of the studies and by MR imaging in 38% (Fig. 6). Regarding the presence of hydromyelia, sonography and MR imaging studies concurred in 73% of the studies. With regard to the location of the hydromyelia in the cord, the examinations concurred in 91% of the studies.

Thickening of the nerve roots of the cauda equina was found by ultrasonography in 14% of the examinations and by MR imaging in 3%. Matching findings between the two modalities were seen in 84%. Masses in the dural sac, whether lipoma, dermoid, or dermoid-epidermoid tumor (Figs. 7, 8), were found in 25% of the sonographic examinations and 44% of the MR imaging studies. Agreement between the two modalities was seen in 65% of the studies.

Associated diastematomyelia (Fig. 9) was found by ultrasonography in 12% of the studies and by MR imaging in 14%, with matching results for the two modalities in 96%.

**DISCUSSION**

Use of ultrasonographic evaluation of the spine, mainly in children, can be traced back to at least 1982. Similarity, the transcutaneous sonography of the postoperative spine can be traced back to at least 1986. Intraoperative ultrasonography of the spinal cord can be traced back to at least 1985. Results of sonographic and MR imaging studies of the pediatric spinal cord have been compared. Although
many articles deal with ultrasonography of the dysraphic spine, and a few reports make comparisons between sonography and MR imaging, we could not find a systematic comparative study between the two modalities for the evaluation of the spine in the follow-up of repaired myelomeningocele. Our study attempts to fill that gap.

The success of the ultrasonographic examination of the postoperative dysraphic spine is highly dependent on the existence of an adequate interlaminar space or bony defect of the posterior elements for the adequate visualization of the spinal canal. If this requirement is met, the patient’s age is no limit. We were successful in visualizing the spinal structures in a 34 year old patient. Because of the lack of adequate window, our examination could not be accomplished in 20% of the examinations. For the same reason, the quality of the successful sonographic studies was only acceptable in 13% and was poor in 1% of the studies, whereas MR imaging had no failures, and 98% of the studies were in the good range.

With most of the cords ending at the lumbosacral region, the agreement between ultrasonography and MR imaging at 82% was fair. This degree of correlation was observed throughout the evaluation of the parameters and is interpreted as due to the described limited quality of some of the ultrasonographic examinations.

In the correlation the sonographic and MR imaging measurements of the cord and dural sac, better

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**Figure 5** Cord pulsation at midlumbar level with M-mode tracing. A, Normal pulsation in a 6 month old girl. B, Absent pulsation in a 4 year old girl.

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**Figure 6** Syrinx (arrows) in a 2 year old boy, sagittal plane. A, Proton density–weighted MR image. B, Ultrasonogram. S, Superior; A, anterior.
agreement was found on the anteroposterior measurements than on the transverse measurements. This is explained by the direction of the ultrasound beam, which finds a perpendicular interface at the anterior and posterior aspects of the structures; this is not the case for the transverse measurements.

Most of the MR imaging studies demonstrated a spinal cord in a dorsal location (93%), whereas ultrasonography identified 39% of the cords in a central, and less frequently, ventral position. The difference is explained by the way the patient is positioned for each study. For MR imaging, the patient is supine, allowing the cord to drop posteriorly. For ultrasonography, the patient is positioned with a flexed spine in the lateral decubitus or sitting up, which tends to move the cord forward. For the same reason, cord adhesions, which are dorsal in most patients, are easier to identify on ultrasonography. As the patient’s spine is flexed and the cord moves ventrally, the dorsal adhesions become easier to see.

Evaluation of cord pulsation has been done in the past with M-mode ultrasonography and with phase-contrast MR imaging, with no definite conclusions in the prediction of retethering of the cord, although, in general, the referenced authors found decreased motion of the cord in the affected patients. We observed that cord pulsation varies with the patient’s position. From our data we conclude that at the lower thoracic area the majority of patients with (65%) or without (93%) cord adhesions have pulsa-

Figure 7 Lobulated lipoma (arrows) in a 2 year old boy, sagittal plane. A, T1-weighted MR image. B, Ultrasonogram. S, Superior; A, anterior.

Figure 8 Epidermoid tumor in a 10 year old boy, sagittal plane. A, T1-weighted MR image (arrow indicates tumor). B, Ultrasonogram. Calipers indicate tumor. S, Superior; A, anterior.
tion. For this reason the presence of thoracic or cervical cord pulsation does not correlate with the severity of the distal cord tethering. At the lumbosacral area, immediately above the area of possible adhesions, a significant number of patients (43%) with cord adhesions also had pulsation. Although minor adhesions cannot be predicted on the basis of cord pulsatility, absence of cord pulsation strongly correlates with tethering. This is based on data from several patients who underwent surgery. In no case was pulsation observed at the site of the adhesions.

Ultrasoundography had less sensitivity in the detection of hydromyelia-syrinx than MR imaging in cases in which the finding was located at the higher levels of the spine. Once sonography identified the hydromyelia, good agreement occurred with MR imaging regarding the location of the lesion.

Evaluation of thickening of the nerve roots of the cauda equina was difficult because of the changing appearance of the roots depending on the patient’s age. The roots are more prominent in the newborn and infant. Because of this, we could not establish an objective criterion for the thickening. Subjectively, a small number of studies seemed to have a positive finding.

Ultrasonography was able to identify masses in the spinal canal ranging from a few millimeters to centimeters. Lipomas were of relatively high echogenicity. Dermoid and epidermoid cysts or tumors were of medium to low echogenicity. A well-defined round or oval contour (convex surface) helped to identify the masses. This was especially true for the dermoid and epidermoid tumors. Many times lipomas had an irregular contour with a nondiscrete appearance, but

Figure 9 Diastematomyelia (arrows) in a 4 year old girl, axial plane. A, T1-weighted MR image. B, Ultrasonogram. P, Posterior.

Figure 10 Diastematomyelia with a bony spur (large arrow) in a 5 year old girl. A, T1-weighted MR image, axial plane. S, Duplicated dural sacs and hemicords. B, Ultrasonogram, sagittal plane. C and small arrows, Hemicord; S, superior; A, anterior.
their increased echogenicity helped in the detection. MR imaging was more sensitive than ultrasonography in the detection of these masses. We interpret the difference on the basis that MR imaging provides a more panoramic visualization of the canal and a tissue-specific signal for some of the masses, especially the lipomas, even in when they have no discrete margins.

Ultrasoundography was able to demonstrate diastematomyelia with good depiction of the duplicated segment of the cord rejoining superiorly and inferiorly. Sonography identified 12 cases of this entity. Two additional cases were identified by MR imaging and not by ultrasonography. Review of these two cases allowed explanation of the difference on the basis of the limited visualization of the canal at the area of interest. In a few cases ultrasonography demonstrated the typical cartilaginous or bony spur separating the two hemicords (Fig. 10).

We found a patient in whom the tethering was due to a thick lipomatous filum (Fig. 11).

In summary, MR imaging has proven itself in the evaluation of the spine and of dysraphic states in particular. This is the result of its ability to demonstrate the entire spinal canal, the extent of the lesions, the anatomic relationship to the surrounding structures, and the possibility of tissue characterization. MR imaging has the advantage of not depending on a bony defect for proper visualization. In turn, it has the drawbacks of being very sensitive to motion, which is not unusual in young patients during the several minutes of the study; it requires sedation and monitoring in young children; and it is relatively expensive. Ultrasonography has none of the described limitations of MR imaging, but it is highly dependent for its success on an adequate vertebral bony window and operator expertise. In those cases that meet these requirements, ultrasonography of the lower spine can yield comparable information to that obtained with MR imaging. With regard to identification of cord adhesions, ultrasonography seems more sensitive than MR imaging.

REFERENCES

