Spine and Spinal Cord Sonography

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Technique and Normal Anatomy

Spinal sonography provides a detailed panoramic view of the spinal canal and its contents in neonates and young infants, being able to characterize nearly all spinal anomalies sufficiently in the first days of life (Gusnard et al. 1986). Color or power Doppler sonography may be used as an adjunct to better characterize soft-tissue masses found on the skin or in the spinal canal (Lowe et al. 2007).

Scanning must be performed with high-resolution/high-frequency 5–15 MHz linear-array transducers (Unsinn et al. 2000; Coley and Siegel 2010). A high-frequency curved-array transducer may be useful to study the craniocervical junction or in older infants when the acoustic window is small (Unsinn et al. 2000; Coley and Siegel 2010; Zieger and Dorr 1988).

In the neonatal period sonographic anatomic detail is excellent, because the incompletely ossified and predominantly cartilaginous spinal arches create an acoustic window that permits transmission of the ultrasound beam (Gusnard et al. 1986). As the baby grows larger and spine ossification advances, sonographic visualization of the spinal canal becomes more limited, less panoramic, and confined to segmental views between ossified posterior spinous elements (Unsinn et al. 2000; Coley and Siegel 2010).

Typically, the newborn is examined in the prone position (Gusnard et al. 1986; Zieger and Dorr 1988). A small pillow placed under the chest and abdomen creates an adequate flexion of the spine, improving the acoustic window between the spinous processes (Coley and Siegel 2010). The decubitus position may be used (Gusnard et al. 1986), always bending the spine. To examine the craniocervical junction and the upper cervical spine, the neck must be flexed (Unsinn et al. 2000). Routinely, sagittal and axial scans of the spinal cord are obtained from the craniocervical junction to the conus medullaris and cauda equina. When the posterior elements of the vertebrae are partially ossified and thus interfere with ultrasound beam transmission, paramedian scans may allow sufficient examination of the spinal cord; the probe is placed paravertebrally to give a 15° medially inclined section (Zieger and Dorr 1988). In older children, although visualization is limited, the tip of the conus medullaris can often be identified (DiPietro 1998). Bony defects (as in malformation or after partial laminectomy) allow the sonographic visualization of spinal structures, irrespective of age (Zieger and Dorr 1988).

High-resolution sonography displays the details of the spinal canal, subarachnoid space, spinal cord, and some emerging nerve roots in axial and sagittal planes.

Direct scanning at the craniocervical junction is easily performed and allows good evaluation of this area in normal infants (Cramer et al. 1986). Good evaluation of cisterna magna, medulla, tonsils, vermis, cervical cord, and central echo complex is possible in most cases (Unsinn et al. 2000). This technique also allows the visualization of subarachnoid blood and clots obstructing the outlet of the fourth ventricle. In patients with Chiari II malformation, a downward dislocation of the medulla and cerebellum is evident; the cisterna magna is obliterated and the normal landmarks of the posterior fossa are no longer seen (Unsinn et al. 2000; Miller et al. 1982; Jequier et al. 1985; Zieger et al. 1988).

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On a sagittal scan (Fig. 1), the spinal cord is a hypoechoic tubular structure with an echogenic center, the so-called central echo complex. The central echo complex is produced by the interface between the myelinated ventral white commissure and the central end of the anterior median fissure. Variations in the shape of the central echo complex seem to reflect varying degrees of flaring of the central end of the anterior median fissure (Nelson et al. 1989). The inconstant residual central canal and islands of residual ependymal cells are clearly not the source of the central echo complex. The gray and white matter that form the mantle of the cord are both hypoechoic and cannot be visualized separately (Gusnard et al. 1986). The signal from the ventral and the dorsal border of the myelon is due to the abruptly changing impedance from solid myelon to liquid cerebrospinal fluid (CSF) in the subarachnoid space (Zieger and Dorr 1988). The anechoic CSF of the subarachnoid space surrounds the spinal cord. The arachnoid-dura mater complex of the thecal sac corresponds to the echogenic border of the spinal canal dorsal and ventral to the subarachnoid space (Unsinn et al. 2000). The lumbar cord exhibits a typically bulbous enlargement and then tapers caudally to the conus medullaris. In normal children, conus level is at or cephalad to the upper limit of L3, in 98–99 % of cases at or above L2 vertebral body (DiPietro 1993; Wolf et al. 1992; Sahin et al. 1997; Hill and Gibson 1995; Wilson and Prince 1989). Longitudinal scans below the level of the conus medullaris show a linear echogenic density representing the filum terminale, surrounded by nerve roots (cauda equina). These latter give rise to a collection of less intense, less sharply defined echoes. The normal thickness of the filum terminale ranges between 0.5 mm and 2 mm at
the level of L5–S1 ([Unsinn et al. 2000; Korsvik and Keller 1992]). According to DiPietro, several methods for assigning vertebral level with sonography can be used (DiPietro 1993):

1. Follow the lowest rib to the spine and call that vertebra T12. Do this on both sides.
2. Identify the lumbo-sacral junction in the longitudinal plane by the change in the angle between the posterior aspect of S1 and L5 (Beek et al. 1994a).
3. Identify the unossified coccyx and follow the five sacral elements cephalad to find L5 (Beek et al. 1994b).
4. Identify the caudal extent of the thecal sac, often found at S2. As the child might have an abnormal number of ribs or lumbosacral vertebrae, all counting methods should be used (DiPietro 2002).

During real-time examination (Fig. 2), a slow dorsal-ventral movement of the spinal cord superimposed on the arterial pulsation can be observed, whereas the fibers of the cauda show a rapid fibrillation (Zieger et al. 1988). Also cord motion due to patient’s breathing and crying can be evaluated. At the border of the surrounding epidural fat, both posterior spinal arteries and the anterior spinal artery can be identified by their pulsations, whereas the venous plexus cannot be distinguished under normal conditions (Zieger et al. 1988).

An axial scan (Fig. 3) of the spinal cord shows the hypoechoic, oval or round spinal cord with the echogenic central echo complex within the anechoic subarachnoid space. The spinal cord originates the paired dorsal and ventral nerve roots. The spinal cord is fixed by the dentate ligaments, which pass laterally to the spinal cord. The ligaments correspond to transversely positioned echogenic arachnoid duplications and can be seen in part of the thoracic spinal canal on axial scans ([Unsinn et al. 2000]).

The size of the spinal cord varies and is broadest in the cervical and lumbar regions. In infants 1–3 months of age, the sagittal diameters of the cervical, thoracic, and lumbar portions of the cord are 5.3 ± 0.28 mm, 4.4 ± 0.42 mm, and 5.8 ± 0.66 mm, respectively (Kawahara et al. 1987).

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**Fig. 2** Normal anatomy of the spinal canal and its contents in a 10-day-old newborn. Dorsal-ventral movement of the cauda equina (arrow) evaluated with real-time ultrasound with M-mode scanning
Variants

Initially, a slight dilatation of the central canal of the spinal cord can be detected in newborns (Fig. 4). This seems to be an incidental finding in healthy newborns and disappears in most cases during the first weeks of postnatal life. It is considered a transient dilatation of the central canal (Unsinn et al. 2000; Toma and Rossi 2001).

The ventriculus terminalis (Fig. 5) is a small cavity of the conus medullaris that forms during the embryonic stages of secondary neurulation (canalization) and retrogressive differentiation and regresses in size during the first weeks after birth. It is a small, ependyma-lined, oval, cystic structure positioned at the transition from the tip of the conus medullaris to the origin of the filum terminale (Sigal et al. 1991). The dilated ventriculus terminalis appears on images as a small ovoid cavity with regular margins; intralesional fluid resembles CSF. This variant causes no clinical symptoms and has a longitudinal diameter of 8–10 mm and a transverse diameter of 2–4 mm (Unsinn et al. 2000; Kriss et al. 1995a, 2000).

The tip of the coccyx can vary in shape and orientation (dorsal angulation or straight course instead of its normal ventral curve) causing a palpable lump in gluteal crease: sonography shows the hypoechoic cartilaginous tip and its orientation.

Fig. 3 Normal anatomy of the spinal canal and its contents in a 10-day-old newborn. (a) Axial scan of the thoracic spinal canal shows the spinal cord (open white arrows), central echo complex (arrowhead), nerve roots (R), subarachnoid space (asterisk), vertebral arch (a), and vertebral body (b). (b) Axial scan of the spinal canal at the level of L3 shows nerve roots (R), filum terminale (white arrow), and subarachnoid space (asterisk)
Congenital Anomalies

Spinal sonography seems to represent a valuable diagnostic tool for congenital anomalies of the lower spine in infants and is recommended as the primary imaging modality in those patients. According to Rohrschneider et al. (Rohrschneider et al. 1996), sonography would allow exactly the same diagnostic accuracy as magnetic resonance imaging (MRI); however, only in selected cases does ultrasound depict the main abnormality with MRI imaging revealing additional findings. Whenever sonographic scans are normal, even MRI does not depict any spinal disorder. In all examinations with abnormal MRI findings, sonography enables detection of the abnormality.

The most common indication for spinal canal sonography is the presence of cutaneous or subcutaneous anomaly of the lower back or an imperforate anus requiring a search for occult tethered spinal cord (DiPietro 2002; Glasier et al. 1990; Scheible et al. 1983).

Ultrasound can be a useful screening tool in newborns with suspected closed spinal dysraphism for two main reasons: first, it occurs in the neonate and young infant in whom the incomplete ossification of posterior elements provides an acoustic window, and second, the associated lack of fusion of vertebral arches further improves the ultrasound visualization of intraspinal structures (Rohrschneider et al. 1996).

Closed spinal dysraphism may be categorized on a clinical basis, depending on the presence of a subcutaneous mass in the back. Closed spinal dysraphisms with a mass are mainly represented by lipomas with dural defects and meningoceles. Closed spinal dysraphisms without a mass may be simple (i.e., tight
filum terminale, filar lipoma, intradural lipoma) or complex (i.e., diastematomyelia, caudal regression) (Tortori-Donati et al. 2000).

Simple midline dimples are the most commonly encountered dorsal cutaneous stigmata in neonates and indicate low risk for spinal dysraphism, especially if the bottom of the pit is visible (Beek et al. 1994b; Kucera et al. 2014). They usually have a low coccygeal location. Low-risk lesions include simple midline dimples (<5 mm in diameter, within 2.5 cm of the anus, no other cutaneous stigmata). Only atypical dimples are associated with high risk for spinal dysraphism, particularly when large (>5 mm), high on the back (>2.5 cm above the anus), or associated with other lesions (Herman et al. 1993). High-risk cutaneous stigmata in neonates include haemangiomas, upraised lesions (i.e., masses, tails, and hairy patches), and multiple cutaneous stigmata (Kriss et al. 1995b; Albright et al. 1989; Gibson et al. 1995). Sonography of the neonatal lumbar spine and canal is the initial investigation also in presence of congenital abnormalities, such as the cloacal exstrophy-anorectal malformation spectrum (CEARMS), which are associated to a variable extent with occult tethered spinal cords (Beek et al. 1995).

Sonographic findings suggestive of closed spinal dysraphism include low position of the conus, nontapered bulbous appearance of the conus, dorsal location of the cord within the bony canal, solid or cystic masses in the distal canal or in soft tissues of the back extending toward the canal, patulous distal thecal sac, and thick filum (Korsvik and Keller 1992).

Fig. 5 Ventriculus terminalis in a healthy 28-day-old newborn. (a) Sagittal and (b) axial scans at the level of the conus tip show a ventriculus terminalis (white arrows).
Cord Tethering

The term “tethered cord syndrome” refers to progressive neurologic deterioration, urinary incontinence, spastic gait, or orthopedic deformities due to traction on a low-lying (below L3) conus medullaris (Tortori-Donati et al. 2000). Cord tethering can occur as a complication of myelomeningocele repair or as the presentation of closed spinal dysraphisms, including spinal lipomas, the tight filum terminale, diastematomyelia, and caudal agenesis.

The ultrasound appearance of tethering is a low-lying or blunt-ended conus medullaris due to the abnormal fixation of the spinal cord. Movement of the spinal cord and cauda equina can be evaluated with real-time ultrasound with M-mode scanning (Fig. 2). Abnormal dorsal fixation of the spinal cord adjacent to the arches of the vertebrae is seen with the patient in the prone position. Typically, the tethered cord is positioned eccentrically and demonstrates reduced or absent undulations at or above the site of tethering (Unsinn et al. 2000). According to Zieger et al. (Zieger et al. 1988), sonographic findings in patients with tethered cord syndrome include low position of the conus (Fig. 6); atypically shaped, dumpy conus; thickened, echogenic filum; dorsal location of the spinal cord with enlarged ventral subdural space (Fig. 7); absent movement of the caudal cord; and caudal soft tissue mass (Fig. 8).

Fig. 6 Low position of the conus medullaris in a 1-day-old newborn. (a) Longitudinal view shows the position of the conus medullaris (open black arrow) at the lower limit of L4. (b) Sagittal T1-weighted MR image confirms the diagnosis.
Tight Filum Terminale

In tight filum terminale, spinal ultrasound shows an abnormally thickened filum terminale, whose transverse diameter is almost consistently greater than 2 mm. Centrally located small cysts or lipomas may be present, but they are commonly detected only by MRI. The tip of the conus medullaris is located...
below L2–3, and reduced or absent spinal cord movements are demonstrated (Coley and Siegel 2010; Korsvik and Keller 1992).

**Hydromyelia and Syringomyelia**

Spinal dysraphism is often associated with hydromyelia or syringomyelia. In hydromyelia, sonography shows a dilated central canal (Fig. 8). In syringomyelia, paracentral cavities connected with a dilated central canal are detected (Naidich et al. 1986).

**Dermal Sinuses**

Dermal sinuses are focal segmental adhesions between cutaneous ectoderm and neural ectoderm. Ultrasound scan of the lumbar spinal canal may depict an echogenic band from the skin to the spinal cord, well detectable within the anechoic subarachnoid space. If the lumen is wide enough to be visualized, the dermal sinus may appear as a triple tract formed by parallel hyperechoic lines around a central hypoechoic space.

Actually, it may be difficult to establish by ultrasonography whether the sinus extends into the spinal canal or to detect possible associated intracanalicular (epi)dermoids (Unsinn et al. 2000; Naidich et al. 1986).

**Spinal Lipoma**

Spinal lipomas are the most common type of closed spinal dysraphism. Ultrasound shows an echogenic intraspinal mass adjacent to the deformed spinal cord. Lipomas (Fig. 9) are homogeneous, well-delineated mass lesions that are slightly more echogenic than epidural fat (Miller et al. 1982; Naidich et al. 1986; Raghavendra and Epstein 1985). Due to its dorsal position, the intradural part of the lipoma causes ventral displacement of the spinal cord or of the cauda. With a normal conus, a thickened echogenic filum indicates lipomatous infiltration (Fig. 8); with absent ascent of the myelon, the tip of the conus lying within the lipoma can no longer be identified (Raghavendra and Epstein 1985). In patients with lipomyelomeningocele, dilated subarachnoid space can be demonstrated.

**Diastematomyelia**

The term diastematomyelia identifies a clefting of the spinal cord into two, possibly asymmetrical hemicords. The ultrasound diagnosis of diastematomyelia may be difficult because the associated posterior spina bifida does provide an acoustic window, but the intersegmental laminar fusion and associated scoliosis may obscure the region of greatest interest. Successful ultrasound, performed in the axial plane, typically shows both hemicords in cross section, lying side-by-side or ventrodorsal to each other, each with a central canal and ipsilateral nerve roots. When present, associated bone spur and hydromyelia may also be visualized (Unsinn et al. 2000; Toma and Rossi 2001; Naidich et al. 1986; Raghavendra et al. 1988).

**Caudal Agenesis (Caudal Regression Syndrome)**

Caudal agenesis, or caudal regression syndrome, refers to a spectrum of findings comprising absence of the lower portion of the caudal spine (Fig. 8). In patients in whom the cord is not tethered (caudal agenesis type I), the distal end of the spinal cord has a characteristic blunted or wedge-shaped appearance. When the cord is tethered (caudal agenesis type II), it is difficult to determine where the conus medullaris ends and the filum terminale begins (Coley and Siegel 2010; Toma and Rossi 2001).
Acquired Diseases

Birth Trauma
Birth trauma to the spinal cord is a serious complication of delivery. Sonography is useful in evaluating neonates with severe spinal cord injury. Sagittal scan shows ventral displacement of the dura mater by an epidural fluid collection (Leadman et al. 1988). Internal cord echogenicity is helpful in demonstrating edema, venous congestion, hematomyelia (hyperechogenicity), and the changes of myelomalacia (hypoechogenicity) (Unsinn et al. 2000; Babyn et al. 1988; Fotter et al. 1994; Filippigh et al. 1994).

Mass Lesions
In mass lesions, spinal ultrasound is useful for disease diagnosis and follow-up, although additional imaging procedures are needed for confirmation of the diagnosis. Spinal neoplasms may be intramedullary or extramedullary, intradural or intraspinal-extradural.

Intramedullary tumors are astrocytomas and ependymomas. They may be solid or cystic, homogeneous or heterogeneous, and produce either focal or diffuse cord enlargement. Real-time techniques reveal the diminished rhythmical movement of the myelon at the infiltrated segment (Zieger et al. 1988; Raghavendra and Epstein 1985; Braun et al. 1983).
In extramedullary intradural tumors, such as schwannomas and neurofibromas, sonography shows the spinal cord displaced and compressed by a solid mass (if an arachnoid cyst is present, the cord is compressed by the cyst). Usually, intradural extramedullary tumors are not distinguishable from intraspinal extradural neoplasms (Ziegler et al. 1988; Raghavendra and Epstein 1985).

Actually, intraspinal extradural neoplasms are vertebral tumors or extensions from intrathoracic or intra-abdominal tumors. A typical occurrence in infants is the intraspinal extension of neuroblastoma (Toma and Rossi 2001; Patel 1985). Sometimes it is possible to detect both the intraspinal and extraspinal parts of the mass (Coley and Siegel 2010; Ziegler et al. 1988; Garcia and Keller 1990).

References


