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A study on the significance of neonatal and infantile spinal sonography

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Abstract
Sonography is an ideal, effective, noninvasive tool for evaluation of the spinal cord in neonatal and early infantile age groups owing to lack of ossification of the posterior elements of spine. Understanding normal anatomical appearances is a prerequisite for the interpretation of various pathologies of the spinal canal and its contents. This review elucidates normal appearances of the spinal cord in this age group, in both axial and sagittal planes.
Usefulness of Doppler sonography is briefly discussed, and special emphasis is placed on normal anatomical variants that may mimic spinal abnormalities. Sonographic appearances of common intraspinal pathologies, both congenital and acquired, are exhaustively described. Key points regarding sonographic diagnosis of important spinal anomalies are emphasized and explained in detail. To conclude, spinal ultrasound is a reliable and widely available screening tool, albeit the usefulness of which is often underestimated.

Keywords: myelomeningocele, spinal dysraphism, spinal sonography, split cord malformation

Introduction
In neonates and infants with suspected spinal and paraspinal anomalies, magnetic resonance imaging (MRI) was and remains the imaging gold standard. However, ultrasonography has recently witnessed tremendous improvement in image quality with the advent of new generation high frequency ultrasound scanners that have brought its diagnostic value on par with that of MRI [1]. in certain conditions. Relative advantages of sonography over MRI include wide and cheap availability, no need for sedation or general anesthesia, and lack of vulnerability to artefacts due to patient movement, cerebrospinal fluid (CSF) pulsation, and vascular flow which can adversely affect MR image quality [2].
In newborns and infants, the spinal arches are predominantly cartilaginous which provide an acoustic window allowing passage of the ultrasound beam. However, in older children, ultrasound suffers from diminished utility due to progressive ossification of the spinal arches. Sonography is a well-established method for investigating the spinal canal, cord, and meningeal coverings and for characterizing nearly all spinal anomalies with high geometric resolution in the neonatal and infantile age groups [3, 4]. The objective of this pictorial review is to present an educational exhibit of spinal sonography encompassing normal appearances, normal anatomical variants, and some common congenital and acquired spinal pathologies.

Technique
Sonography of the spine should be performed with a high frequency (7-12 MHz), high resolution linear transducer. Both axial and sagittal plane scanning is mandatory. The axial scanning can either be performed in a cranial to caudal direction or caudocranial direction. Localization of the conus medullaris is crucial for the detection of low-lying cord or high termination of cord. Location of conus should be interpreted in relation to the lumbar vertebral bodies. Sagittal scanning should be performed both in the median and paramedian planes.

Normal Appearances
Axial scan
The spinal cord is seen axially as a round or oval hypoechoic structure with central echogenicity within the anechoic subarachnoid space [Figure 1]. Paired dorsal and ventral nerve roots are seen to arise from the cord. The vertebral bodies and arches are seen ventral to the spinal cord as echogenic structures with distal acoustic shadowing [Figure 2]. The paravertebral muscles are seen below the level of L2 vertebra [1, 6]. The cord diameter is variable and is the largest at the cervical and lumbar levels, which are known as cervical and lumbar "enlargements" (which give rise to nerve roots of respective nerve plexuses). In terms of dorsal/ventral orientation, the cord normally lies a third-to-half way between the anterior and posterior walls of the spinal canal [1].

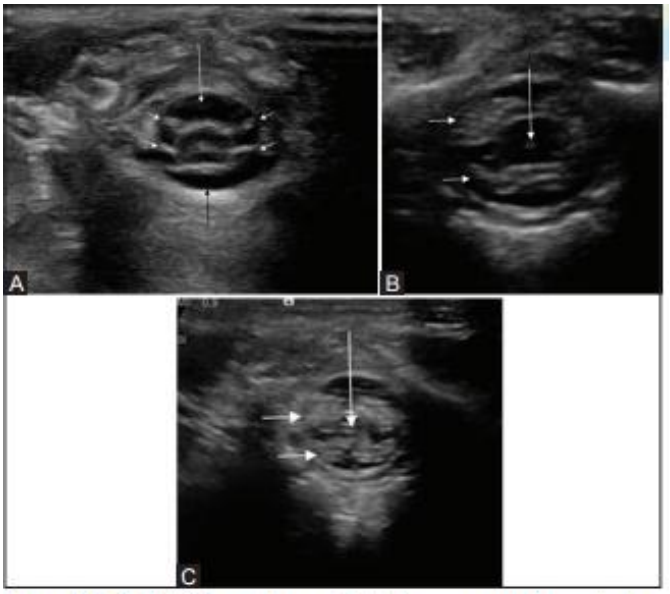

Figure 1 (A-C): (A-C) Normal sequential axial sonogram of thoracolumbar spine. The spinal cord appears hypoechoic, covered by an echogenic pial lining, and surrounded by anechoic CSF spaces. Note that the ventral (black arrow) and dorsal (white arrow) CSF spaces are nearly equal in dimension. The nerve roots appear echogenic (small arrows). On a more caudal section (B), there is normal enlargement of cord at conus medullaris, which tapers distally. Hence, a more caudal section would reveal only a bunch of nerve roots as echogenic structure (block arrows), with a central hypoechoic filum terminale (arrow in C)

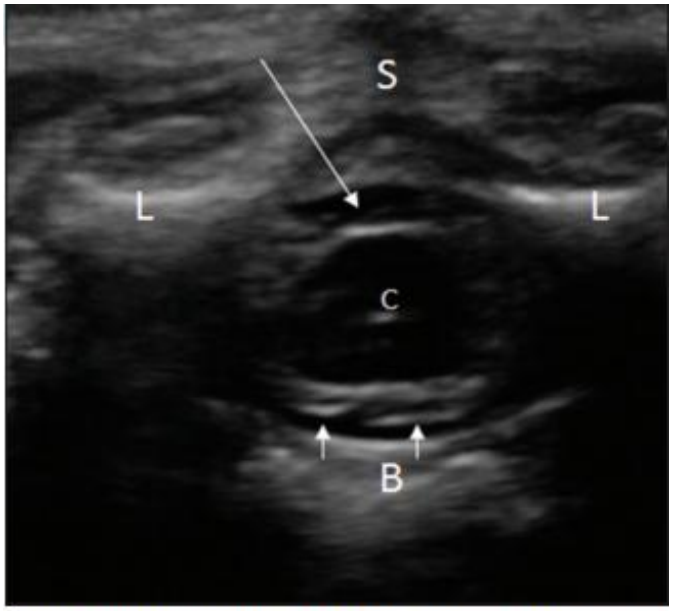

Figure 2: Normal conus medullaris on axial image. The spinal cord is seen as hypoechoic rounded structure, surrounded by anechoic CSF (arrow). The pial margin on the cord surface appears echogenic; the central canal (C) also appears echogenic. The ventral roots of spinal nerves appear as echogenic strands (small arrows). Note the echogenic laminae (L), unossified spinous process (S). and vertebral body (B) of a lumbar vertebra

Sagittal scan

The cervical cord and craniocervical junction can be difficult to evaluate on ultrasonography. On sequential scanning from cervical to lumbar level, the cervical and lumbar enlargements are well visualized. A systematic scanning from both the parasagittal to mid-sagittal planes is required [Figure 3]. While the parasagittal image is ideal for the evaluation of the paraspinal structures, the mid-sagittal image is ideal for the evaluation of the cord [6, 7]. The caudal end of the spinal cord is represented by the conus medullaris and filum terminale [Figure 4]. The conus is identified as the apex of the taper of the distal spinal cord, and its level is designated according to the adjacent intervertebral disk space or mid-vertebral body. For identifying the vertebral level, palpable landmarks such as the tip of the lowest rib and the iliac crest which correspond to the levels of the L2 and L5 vertebrae, respectively, may be used. Alternately, the lumbosacral junction may be identified by looking for the first clear angulation in the caudal spine with the L5 vertebral body lying immediately cranial to this level. In a healthy newborn, the tip of the conus medullaris is located between L1 and L2 vertebral levels. This method can be fallacious in cases of transitional vertebra.

Another method of detection of vertebral level is to identify the coccyx and counting cranial to it [6, 7]. The normal cord and nerve roots show pulsatile movements which must be specifically looked for to rule out cord tethering.

Normal sacrum in mid-sagittal scanning

Sacrum should be evaluated in the sagittal plane [Figure 5] for the presence of the spinal dysraphism. Because the posterior elements of the sacrum are unossified at this age, they appear hypoechoic.

Doppler ultrasound imaging of the spinal cord

Although not routinely used for the evaluation of vascular anatomy and abnormality of spinal canal, Doppler ultrasound with the new generation scanners on a high frequency transducer can provide an insight of the vascular anatomy in considerable detail [Figure 6].

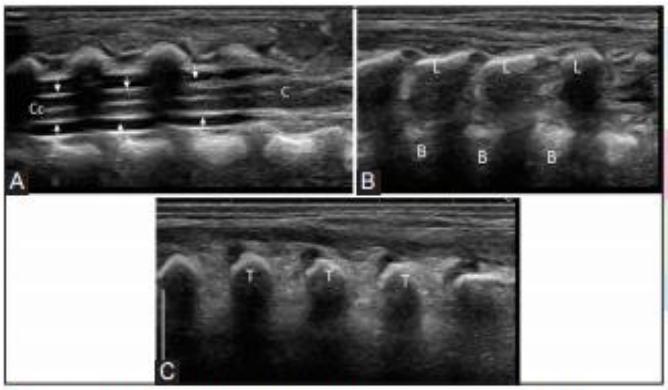

Figure 3 (A-C): Mid-sagittal (A) to parasagittal (B) and further lateral (C) sagittal image of the thoracolumbar spine. The spinal cord is visualized as a hypoechoic tubular structure with a central echogenicity (central echo complex) representing the central canal (C, c). The pial lining is shown with small arrows. Note the enlargement of cord at the conus medullaris (C). The arachnoid-dura mater complex of the thecal sac is represented by the echogenic borders of the spinal canal seen anterior and posterior to the CSF filled anechoic subarachnoid space. The spinous process of the vertebral bodies are visible in a mid-sagittal section (S), the laminae (L) and transverse processes (T) seen more laterally

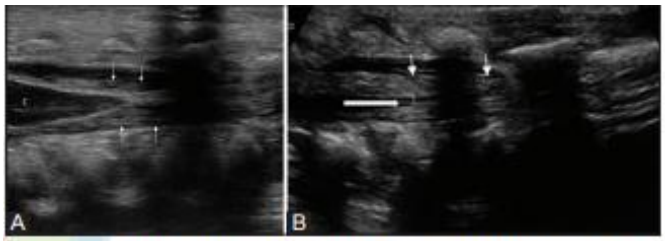

Figure 4 (A and B): (A and B) Normal conus medullaris and filum terminale in sagittal section. The conus medullaris (c) tapers into filum terminale (block arrow, within the cursors in B); which appears as a cordlike structure surrounded by the echogenic cauda equina nerve roots (arrows)

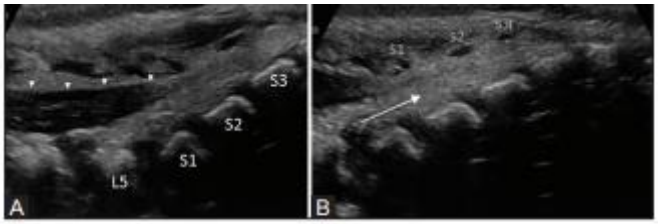

Figure 5 (A and B): (A and B). Normal sacrum mid-sagittal view. The spinous processes are marked in B. The dura (arrowheads) ends at S1 level. Echogenic nerve roots are seen within the spinal canal. Beyond the dural attachment, the space within the sacral spinal canal is occupied by echogenic fatty tissue (arrow)

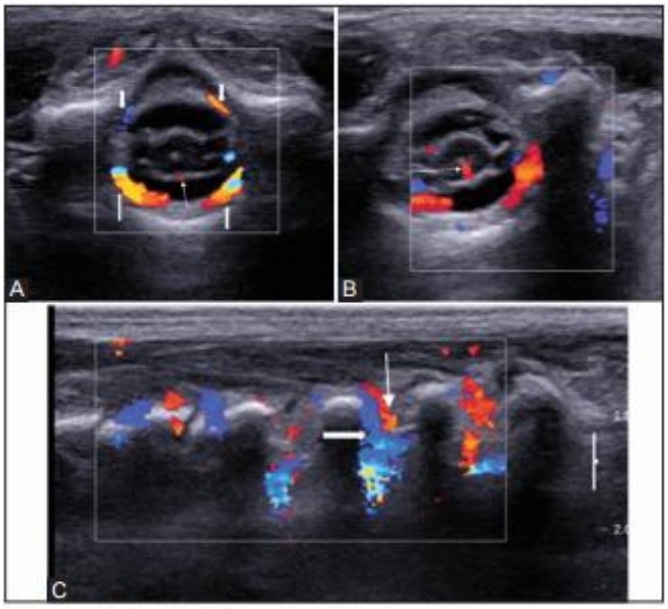

Figure 6 (A-C): (A-C) Doppler USG of normal thoracic spine. Axial images with Doppler interrogation (A, B) show the anterior spinal artery (arrow in A); the sulco-commisural artery (arrow in B) and the ventral and dorsal dural arcades (block arrows). The parasagittal image (C) reveals the dorsal division of the dorsal spinal artery (arrow) with accompanying vein (block arrow) arising from the segmental arteries at multiple levels

Normal Variants

Many normal anatomical variants such as ventriculus terminalis and transient dilatation of the central canal are often incidentally detected on spinal ultrasonography (USG).

Ventriculus terminalis

Canalization and retrogressive differentiation of the caudal end of the developing spinal cord gives rise to a small, ependymal lined, oval, cystic structure (ventriculus terminalis) [Figure 7] located at the transition from the tip of the conus medullaris to the origin of the filum terminale [8]. This structure usually measures 8-10 mm in longitudinal diameter and 2–4 mm in transverse diameter [8]. This condition is asymptomatic and regresses in the first few weeks after birth.

Transient dilatation of the central canal

Mild central canal dilatation [Figure 8] is an often detected incidental finding in many healthy newborns in the first few weeks of life which disappears later on. It should be differentiated from syringomyelia, which persists on follow-up imaging.

Filum terminale cysts

These refer to anechoic, centrally located, thin-walled unilocular cysts within the filum terminale, which appear spindle-shaped in the sagittal plane and round in the axial plane. When found isolated, they do not carry any clinical significance.

Spinal Pathologies

Spinal pathologies can be broadly categorized as congenital malformations and acquired diseases. Congenital anomalies are attributed to missteps in embryological development of the spinal cord, which result in a diverse range of pathologies that present as myriad sonographic appearances. On the other hand, acquired intraspinal diseases following birth trauma or intraspinal extension of neurogenic tumors can also be detected with ultrasound.

Congenital anomalies

Open spinal dysraphism M e n i n g o c e l e, m ye l o m e n i n g o c e l e, m ye l o c e l e, hemi-myelocele, hemi-myelomeningocele, etc, are included in the open spinal dysraphism group. These lesions are not skin covered. Myelomeningoceles constitute >98% of open spinal dysraphism [9]. In myelomeningocele [Figure 9], an expansion of the ventral subarachnoid space displaces the neural placode dorsally resulting in portions of the spinal cord, nerve roots, and leptomeninges lying within the sac; whereas in myelocele, the neural placode remains flush with the skin surface and there is no expansion of ventral CSF space [9].

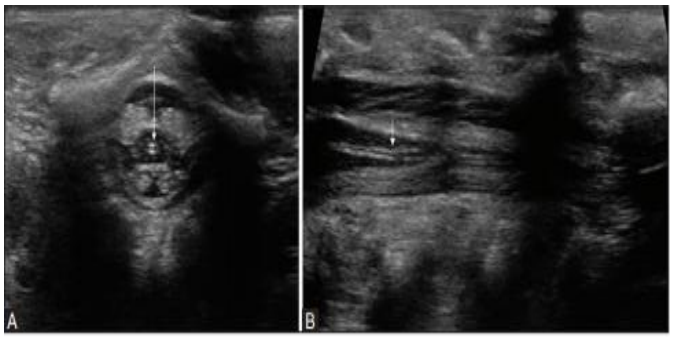

Figure 8(A and B): Axial (A) Sagittal (B) sonogram of the distal conus medullaris and filum terminal revealing mild dilation of the canal (arrow) in a healthy newborn

Some authors caution against preoperative imaging for these anomalies owing to risk of infection or injury [5, 6]. However, by observing strict aseptic precautions, including covering the probe with a sterile cover and using sterile gel, proper sonographic examination can be performed using the intact

normal skin surrounding the parchment membrane of the lesion as the acoustic window. In addition to local examination, sonography is also useful in recognition of associated malformations such as Chiari II syndrome, tethered cord, hydromyelia/syringomyelia, and arachnoid cyst [6].

Ultrasound also finds an important role in post-repair cases because cord tethering is a common postoperative complication on account of postoperative scarring. When myelomeningocele or myelocele is associated with split cord malformation (discussed later), they are termed as hemi-myelomeningocele/hemi-myelocele.

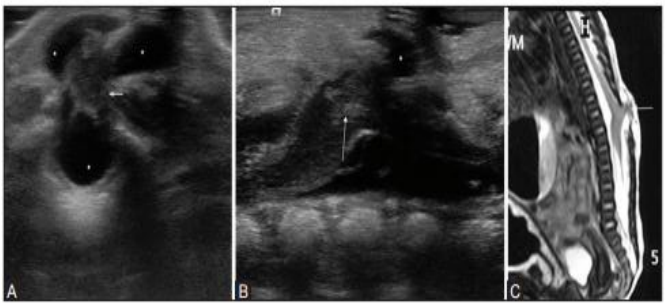

Figure 9(A and B): Lumbar myelomeningocele. Axial (A) Sagittal (B, C) US images reveal herniation of the couns (arrow) with an expansion of ventral CSF space (asterisk). Sagittal T2-weighted MR image reveals the defect in posterior elements of upper lumbar vertebrae with herniation of neural tissue and CSF spaces (arrow)

Conclusion

Ultrasound is an inexpensive, easily performed, widely available, radiation free investigative technique, which is now considered to be the initial imaging modality of choice for investigating the spinal cord in neonates and infants up to 6 months of age. Its wide ranging diagnostic utility coupled with its high accuracy, especially in expert hands, plays a pivotal role in choosing the type and timing of therapeutic intervention. In addition, spinal sonography also carries therapeutic applications and is useful as an image guidance modality for certain procedures. However, despite all these advantages, spinal ultrasound remains an underutilized and often underestimated modality largely due to lack of awareness. Thus, popularization of spinal sonography for diagnostic and therapeutic uses in neonatal and early infantile population and spreading awareness regarding its merits is an urgent need of the hour.

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