Diagnostic Approach to Pediatric Spine Disorders

Andrea Rossi, MD*, Carola Martinetti, MD, Giovanni Morana, MD, PhD, Mariasavina Severino, MD, Domenico Tortora, MD

KEYWORDS

• Spinal cord • Spine • Children • Dysraphisms • Myelitis • Myelopathy

KEY POINTS

- Understanding embryologic steps and developmental features is crucial for a correct analysis of MR images in pediatric patients.
- Technical requirements (ie, choice of study protocols, sequences and so forth), must be tailored to address the clinical problem in the rapidly changing environment of the growing pediatric spine.
- Clinical presentations in children with severe, function-threatening disorders can be subtle and long-standing, leading to delays in the diagnosis.
- A working knowledge of the main indications and limitations for spinal imaging in children, including pitfalls or normal variants, is fundamental.

INTRODUCTION

Imaging of the spine and spinal cord is commonly required in the pediatric age group to address a wide array of medical conditions, sometimes presenting in the emergency room. MR imaging has made the diagnosis of these disorders easier, faster, and more accurate, thereby enhancing the possibility of an early and case-tailored treatment, mainly thanks to its multiplanar imaging and tissue characterization capabilities and lack of radiation exposure. Although the MR imaging picture in patients with spinal disorders may appear complicated and puzzling even to experienced observers, a rational approach focusing on a correlation of clinical, embryologic, and neuroradiological data greatly facilitates the diagnosis in most cases. In this article, the principal indications for spinal MR imaging in the pediatric age group are discussed, along with a description of the embryologic steps that lead to the formation of the spine, the main technical issues pertaining to pediatric spinal MR imaging, and a few pitfalls or variants that may simulate disorder.

EMBRYOLOGY

The development of the spine and spinal cord is a highly coordinated phenomenon that begins very early during gestation. It consists of several consecutive steps, which are briefly described here.

During gastrulation, the bilaminar embryonic disc, formed by epiblast (future ectoderm) and hypoblast (future endoderm) is converted into a trilaminar disc because of formation of an intervening third layer, the mesoderm. This process begins by day 14 or 15 when the primitive streak, a stripe of thickened epiblast composed of totipotential cells, appears along the midline of the inferior portion of the dorsal surface of the embryo. The primitive streak has a knoblike cranial termination called the Hensen node. Epiblastic cells start migrating toward the primitive streak and pass inward at the primitive pit, a central depression of the Hensen node, to ingress the interface between the epiblast and the hypoblast; the first cells to ingress displace the hypoblast and form the endoderm, whereas subsequent waves of epiblastic

Disclosure: The authors have nothing to disclose.
Neuroradiology Unit, Istituto Giannina Gaslini, Via Gerolamo Gaslini, 5, Genova 16147, Italy
* Corresponding author.
E-mail address: andrearossi@gaslini.org

Magn Reson Imaging Clin N Am 24 (2016) 621–644
http://dx.doi.org/10.1016/j.mric.2016.04.001
1064-9689/16/$ – see front matter

cells migrate laterally above the endoderm to form the mesoderm. Those cells migrating along the midline of the ectoderm-endoderm interface form the notochord. The notochord is the foundation of the axial skeleton and extends throughout the length of the future vertebral column. From the mesoderm surrounding the neural tube and notochord, the skull, vertebral column, and the membranes of the brain and spinal cord are developed. The notochord is required for the ectoderm to become neural ectoderm and form the neural tube.[1]

Establishment of the neural plate marks the onset of primary neurulation. This process occurs about day 18, when the neural plate starts bending, forming paired neural folds. In the following days, these progressively increase in size and approach each other to eventually fuse in the midline to form the neural tube. According to the traditional zipper model, closure of the neural tube occurs first at the level of the fourth somite (future craniocervical junction) and then proceeds both cephalad and caudad. The cranial extremity of the neural tube (rostral or anterior neuropore) closes at day 30, whereas the caudal extremity (caudal or posterior neuropore) closes at day 31. Closure of the posterior neuropore marks the termination of primary neurulation.[2,3]

The posterior neuropore, that is the caudal extremity of the primary neural tube, corresponds to the 32nd somite (ie, the future third sacral metamere). The segment of the spine and spinal cord caudad to somite 32 is formed by secondary neurulation. This embryologic step begins immediately after completion of primary neurulation and proceeds until approximately gestational day 48. During secondary neurulation, the tail bud, a mass of cells deriving from the caudal portion of the primitive streak, lays down an additional part of the neural tube caudad to the posterior neuropore. This cord segment differs from the one formed by primary neurulation in several ways. Although the primary neural tube results from an upfolding of the lateral borders of the neural plate that join at the midline, the secondary neural tube is formed by an infolding of the neural plate, creating an initially solid medullary cord that subsequently becomes cavitated.[4,5] The fate of the secondary neural tube is to undergo an incompletely understood process of regression, degeneration, and further differentiation, called retrogressive differentiation. This process results in the formation of the tip of the conus medullaris, which contains the lower sacral and coccygeal cord metameres, and the filum terminale, a fibroconnectival structure practically devoid of neural elements. The conus medullaris contains a focal expansion of the ependymal canal called the terminal ventricle, representing the remnant of the lumen of the secondary neural tube.

The development of the vertebral column proceeds simultaneously with that of the neural tube. At first, the paraxial trunk mesoderm is unsegmented. As development proceeds, epithelial spheres, called somites, are formed and undergo maturation in a cephalocaudal gradient. This maturation leads to dissociation of the epithelial somite, forming the dermatome (dorsal), the myotome (intermediate), and the sclerotome (ventral). The dermatome is located underneath the surface ectoderm. It gives rise to dermal cells for the dorsal moiety of the body. The myotome gives rise to all striated muscle fibers of the body. The sclerotome differentiates into cartilaginous cells of the vertebrae, cells of the intervertebral discs and ligaments, and cells of the spinal meninges. Furthermore, the somite gives rise to endothelial cells. The sclerotome is first located ventrally, and then it spreads to enwrap the entire neural tube forming at its dorsal face the so-called dorsal mesoderm, which will insinuate itself between the neural tube and the surface ectoderm after disjunction. On a next step of differentiation, the sclerotomes divide in half horizontally; the bottom half of one fuses with the top half of another to form the vertebrae. Notochordal remnants between the vertebrae become the nucleus pulposus within the intervertebral disc.[6]

IMAGING PROTOCOLS

Imaging of the spine and spinal cord in the pediatric age group is best accomplished with MR imaging in almost all cases,[7] whereas other modalities play a complementary role in selected indications. Sonography can be used as a valid imaging modalities in newborns and small infants[7,8] but is limited by the degree of ossification of the neural arches of the vertebral columns other than by individual operator expertise. Computed tomography (CT) offers a detailed depiction of the structure of bone, but its use must be weighed against radioprotection issues; in principle, CT should be reserved for the elucidation of specific features and should always be tailored to the minimum possible field of view so as to minimize unnecessary radiation exposure.[9]

A significant issue in pediatric MR imaging in general is the capability of small patients to cooperate long and well enough to obtain quality imaging studies. In general, children may be sufficiently cooperative at age 5 years, although specific conditions, such as acute illness or psychomotor delay, may change this. Younger or severely ill