Myelin, Myelination, and Corresponding Magnetic Resonance Imaging Changes

Saurabh Guleria, MD[a,*], Teresa Gross Kelly, MD[b]

KEYWORDS

• White matter • Myelination • Magnetic resonance imaging

KEY POINTS

- Myelination of the white matter occurs in an orderly and predictable fashion.
- Magnetic resonance (MR) imaging is the most useful modality for in vivo imaging of white matter maturation.
- The anatomic standard MR imaging sequences detect myelination during the early years of life, whereas advanced imaging techniques that include diffusion-weighted imaging, diffusion tensor imaging, and spectroscopy, are most useful later.
- Familiarity with these normal imaging patterns of myelination is essential for providing an accurate assessment of normal myelination and thus identification of disease processes.

INTRODUCTION

An important component of brain maturation involves myelination of white matter, which is essential for normal brain function and enables rapid conduction of nerve signals across the neural systems responsible for higher order motor, sensory, and cognitive functioning. Myelination begins during the fifth month of fetal life and continues throughout life in an orderly pattern thought to be consistent with evolving neural functionality.[1] Detailed postmortem histologic studies provide the most accurate analysis of normal or abnormal myelination but are not suited to investigating the longitudinal relationship between myelination and behavioral maturation. Magnetic resonance (MR) imaging is superior in assessing myelination of the brain noninvasively and it surpasses both computed tomography[2] and ultrasound in contrast resolution. In the past decade there have been rapid advancements in technology resulting in more sophisticated and higher strength magnets, introduction of new imaging sequences, and refinements of existing sequence protocols that have furthered interest and understanding of myelination. This article discusses the composition of myelin, the process of myelination, and the usefulness of MR imaging for assessment of white matter maturation.

MYELIN STRUCTURE

The structure of myelin is rich in lipid and protein, and it is seen in both the central nervous system (CNS) and peripheral nervous system.[3,4] In the CNS, myelin is primarily found in white matter, although it is also present in gray matter, but in smaller quantities. The long sheets of CNS myelin are composed of several segments of myelin that are modified extensions of oligodendroglial cell processes that wrap around the axon in a concentric lamellar fashion (**Fig. 1**). The axon is not

Disclosures: The authors have no disclosures.
[a] Pediatric Radiology, Children's of Alabama, University of Alabama at Birmingham, 1600 7th Avenue South, Lowder Building Ste. 306, Birmingham, AL 35233, USA; [b] Imaging, Children's Hospital of Wisconsin, Medical College of Wisconsin, 9000 W Wisconsin Avenue, Milwaukee, WI 53226, USA
* Corresponding author.
E-mail address: saurabh.guleria@childrensal.org

Radiol Clin N Am 52 (2014) 227–239
http://dx.doi.org/10.1016/j.rcl.2013.11.009
0033-8389/14/$ – see front matter

continuously wrapped by myelin; gaps are interposed in which the bare axon is exposed to the interstitial space, termed nodes of Ranvier. The nodes of Ranvier are also the sites of multiple sodium channels.[5] The myelinated portion of the axon located between the nodes of Ranvier is called the internodal region, which can further be divided into 2 distinct domains, namely the paranodal loops and compact myelin. Paranodal loops facilitate ion exchange at the node of Ranvier, whereas compact myelin inhibits ion exchange during nerve conduction.

The myelin bilayer is made up of approximately 80% lipid and 20% protein (**Fig. 2**). The intracellular and extracellular space between the bilayers is filled with water, which makes up approximately 40% of the weight of myelin.

The protein components of myelin's ultrastructure include[5]:

1. Myelin basic protein, which comprises approximately 30% of the myelin proteins and is localized at the cytoplasmic surface of compact myelin.
2. Proteolipid protein (PLP), which has 4 membrane-spanning domains that make up about 50% of the myelin proteins. The PLP maintains the extracellular spacing of compact myelin by virtue of its electrostatic interactions with myelin lipids.
3. Cyclic nucleotide phosphodiesterase, which is the least abundant protein and makes up about 4% of the myelin proteins. It is concentrated on the cytoplasmic side of the myelin lamellae.
4. Myelin-associated glycoprotein, which constitutes less than 1% of the myelin proteins, but probably helps oligodendrocyte processes distinguish between myelinated and unmyelinated axons in the CNS.
5. Myelin oligodendrocyte glycoprotein (MOG), which is mainly confined to oligodendrocyte bodies and is seen in the outermost surface of the myelin sheath. The precise function of MOG is unknown, but it may have a role in defining the structural integrity of the myelin sheath.

The lipid components of myelin's ultrastructure include[6]:

1. Cholesterol, which plays a critical role in the assembly and integrity of myelin and is mostly found in the outer layer of the cell membrane.
2. Phospholipids, which comprise approximately one-third of the total lipids, which are hydrophobic and are located on the cytoplasmic side of the cell membrane.
3. Glycosphingolipids, which account for approximately one-third of the total lipids and include cerebrosides, sulfatides, globosides, and gangliosides. The concentration of cerebroside in the brain has been shown to correlate proportionally with the amount of myelin present.[7]

The composition of myelin is largely preserved among mammalian species. There are also regional variations within a single species such as spinal cord myelin, which has a higher lipid/protein ratio than myelin from brain tissue.[6]

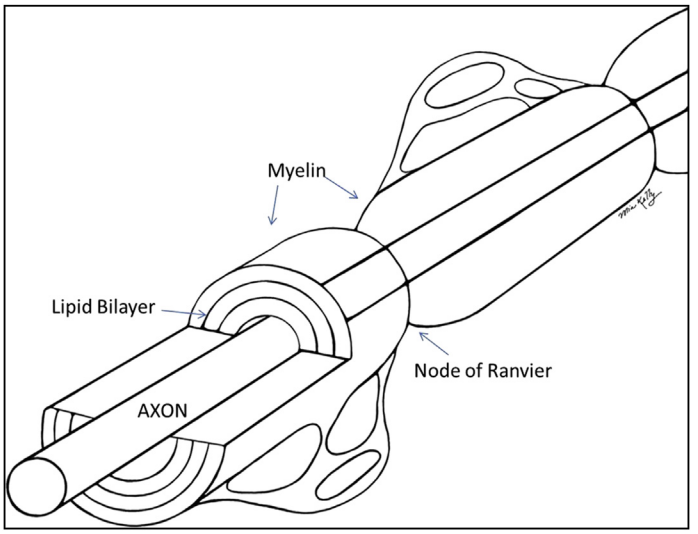

Fig. 1. Cross section of a myelinated axon showing formation of myelin sheath from extension of a cell process from an oligodendrocyte.