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Vascular Diseases of the Spinal Cord: Infarction, Hemorrhage, and Venous Congestive Myelopathy

Shawn M. Vuong, MD,* William J. Jeong, MD,* Humberto Morales, MD,†,‡ and Todd A. Abruzzo, MD*,‡,§

Vascular pathologies of the spinal cord are rare and often overlooked. This article presents clinical and imaging approaches to the diagnosis and management of spinal vascular conditions most commonly encountered in clinical practice. Ischemia, infarction, hemorrhage, aneurysms, and vascular malformations of the spine and spinal cord are discussed. Pathophysiologic mechanisms, clinical classification schemes, clinical presentations, imaging findings, and treatment modalities are considered. Recent advances in genetic and syndromic vascular pathologies of the spinal cord are also discussed. Clinically relevant spinal vascular anatomy is reviewed in detail.
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Introduction

From 1882-1886, Albert Wojciech Adamkiewicz published arguably his greatest works concerning the anatomy of the vasculature of the spinal cord. His work illuminated the significant variability and remarkable anastomotic network supplying blood to the spinal cord. The contributions he provided to anatomy and medicine have led to the eponymous term "Adamkiewicz artery."[1] Unfortunately even with Dr Adamkiewicz publications, modern medical literature often fails to provide accurate and consistent terminology for the arteries that supply the spinal cord. As as result, the vascular anatomy and vascular pathology of the spinal cord has continued to be elusive and incompletely understood by physician subspecialists in the neurosciences.

This article reviews a wide range of spinal vascular pathology including intraspinal hemorrhage, vascular malformations of the spine, spinal arterial aneurysms, and conditions that produce arterial ischemic myelopathy and venous congestive myelopathy. Each pathology is considered according to clinical presentation, commonly used clinical classification systems, differential diagnosis, imaging findings, and commonly employed treatment strategies. The anatomical foundations of these diseases are outlined and discussed in relation to disease pathogenesis.

*Department of Neurosurgery, University of Cincinnati College of Medicine, Cincinnati, OH.
†Department of Radiology, University of Cincinnati College of Medicine, Cincinnati, OH.
‡Comprehensive Stroke Center, University of Cincinnati Neuroscience Institute, Cincinnati, OH.
§Department of Radiology, Cincinnati Children's Hospital and Medical Center, Cincinnati, OH.
Address reprint requests to Todd A. Abruzzo, MD, Department of Neurosurgery at the UC College of Medicine, 234 Goodman St, Cincinnati, OH 45267. E-mail: todd.abruzzo@cchmc.org

Spinal Vascular Anatomy

Arterial Supply

Intrinsic Circulation of Spinal Cord

The intrinsic arterial or parenchymal system is subdivided into a central (centrifugal) system and a peripheral (centripetal or vasocorona) system. The central system is primarily responsible for supplying the gray matter at the center of the spinal cord. Blood flow runs from deep to superficial, and is supplied by penetrating branches of the central sulcal arteries (100-250 μ diameter), which branch off the anterior spinal artery and course into the ventral median sulcus before piercing the sulcal surface of a hemicord. The peripheral system supplies blood primarily to the white matter via radial penetrating arteries ($\leq$50 μ diameter) that course from superficial to deep perpendicular to the superficial pial surface of the spinal cord. The penetrating radial arteries of the peripheral system arise

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from the vasocorona that receives its supply from the posterior spinal arteries. Given the much larger contribution by the anterior spinal artery, supplying both the central system and parts of the peripheral system, the anterior spinal artery ends up supplying two-thirds to four-fifths of the cross-sectional area of the spinal cord. The posterior spinal arteries then supply one-third to one-fifth of the spinal cord.[2,3] The anteroposterior asymmetry of spinal cord blood flow accounts for the significant size differential between the anterior spinal artery (200-500 μ diameter) and the posterior spinal arteries (100-200 μ diameter).

Deep intrinsic, intrasegmental anastomoses between the central and peripheral arterial systems of the spinal cord are not hemodynamically significant, and deep intrinsic intersegmental anastomoses between consecutive rostrocaudal segments of the central and peripheral systems are nonexistent. Consequently, the only meaningful anastomoses within the intrinsic spinal cord circulation are found at the superficial level between the anterior and posterior spinal arteries at the conus medullaris (cruciate anastomosis or conus arcade).

Extrinsic Arterial Inflow to the Intrinsic Spinal Cord Circulation

The arterial inflow to the anterior spinal artery (and corresponding intrinsic central circulation) is delivered by the medullary rami of the intradural vertebral arteries (at the inferior margin of the medullary olives) and the segmental radiculomedullary arteries, which follow the ventral spinal nerve roots. The arterial inflow to the posterior spinal arteries (and corresponding superficial intrinsic circulation) is derived from the intradural vertebral arteries, posterior medullary segment of the posterior inferior cerebellar arteries and segmental radiculopial arteries, which follow the dorsal spinal nerve roots. The radiculomeningeal arteries supply the main spinal nerve root, its dural sleeve and the dural sac of the spinal cord, cauda equina, and filum terminale (Fig. 1).

Functional, dominant segmental radiculomedullary arteries are present at only a few vertebral levels as the majority involute during normal embryologic development. *Owing to the significant reliance on blood supply from these dominant segmental arteries, watershed areas exist between them, particularly at the upper thoracic region.*[2]

In the cervical spine, 1 or 2 segmental radiculomedullary arteries are typically present (artery of the cervical enlargement at C3 with or without accessory artery of the cervical enlargement at C6, C8, or both). The inflow to these vessels is variable, but most commonly comes from a vertebral artery. Alternative anatomical sites include the occipital artery, the ascending pharyngeal artery, the ascending cervical artery (branch of thyrocervical trunk), and deep cervical artery (branch of costocervical trunk).

In the thoracolumbar spine, there is most often a single dominant radiculomedullary artery (artery of Adamkiewicz) in the lower thoracic region, though 4-6 radiculomedullary arteries may be present. In approximately 70% of patients, an additional "dominant" radiculomedullary artery arises in the upper thoracic region (artery of Von Haller) between the left T3 and T7 vertebral levels.[4] The artery of Adamkiewicz usually arises between the T8 and L3 vertebral levels (most commonly at T9), on the left side in greater than 80% of cases. This right-left asymmetry likely relates to the position of the aorta on the left side of the spine and selective regression of the more distant right-sided radiculomedullary arteries. The supply to the thoracic radiculomedullary arteries is most often derived from the spinal branch of a posterior intercostal artery, but it may be derived from a bronchial artery. When the dominant radiculomedullary artery arises above the T8 vertebral level, an additional radiculomedullary artery arises in the lumbar region (artery of the conus medullaris). This variant is seen in only 15% of patients and is most commonly supplied by the spinal branch of a lumbar artery arising at the L1-L3 levels.

Segmental and Nonsegmental Extra-Axial Spinal Circulation

The arterial supply to the spine depends heavily on supply from the segmental arteries and their anastomotic network. The segmental arteries travel posteriorly sometimes arising from a common trunk before they split into 3 major branches. Nomenclature of the branches varies among many sources, likely because of the difference in historic terminology and the naming schemes provided by embryology.

The segmental arteries include the paired posterior intercostal arteries and the paired lumbar arteries. The posterior intercostal arteries arise from the costocervical trunks of the subclavian arteries, the supreme intercostal arteries, the bronchial arteries, or directly from the descending thoracic aorta. The first 4 pairs of lumbar arteries arise from the abdominal aorta. Below the L4 level, the lumbar spinal arteries arise from the iliolumbar arteries (branches of the common or internal iliac arteries). The lateral sacral arteries typically arise from the iliolumbar arteries, and the median sacral artery arises directly from the aortic bifurcation.

The segmental arteries typically distribute a spinal branch, which enters the spinal canal through an intervertebral neural foramen, a middle trunk (also known as dorsal or posterior branch), which supplies the dorsal spinal musculature, spinal laminae, and spinous processes; and a costovertebral branch (also known as lateral, ventral, or collateral branch), which supplies the rib or transverse or both process of the spine. *The spinal branch of each segmental artery divides into 3 major tributaries:* (1) *a radicular artery,* (2) *a ventral epidural branch artery, and* (3) *a dorsal epidural branch artery. The radicular artery subsequently divides into ventral and dorsal branches that terminate in radiculomedullary, radiculopial, and radiculomeningeal arteries.*[2,5-9]

Venous Drainage

In contrast to the intrinsic arterial system of the spinal cord, the intrinsic medullary venous system drains the spinal cord symmetrically in a centrifugal manner. The venous drainage of the deep central regions of the spinal cord (mostly gray matter) is symmetrically divided between the anterior median spinal vein and the posterior median spinal vein, which drain in a centrifugal direction. The superficial regions of the spinal