



SHORT REPORT

Angio-CT Imaging of the Spinal Cord Vascularisation: A Pictorial Essay

G. Melissano*, E. Civilini, L. Bertoglio, F. Calliari,
A. Campos Moraes Amato, R. Chiesa

Scientific Institute H. San Raffaele, Chair of Vascular Surgery, Vita Salute San Raffaele University, Milan, Italy

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Abstract Knowledge of the spinal cord (SC) vascular supply is important in patients undergoing procedures that involve the thoracic and thoraco-abdominal aorta; the SC vasculature, however, has a complex and highly variable anatomy. Recent breakthroughs in imaging methods have expanded the non-invasive diagnostic ability to determine a patient's spinal cord vascular pattern, particularly in detecting the presence and location of the artery of Adamkiewicz. CT is the imaging modality of choice for most patients with thoracic and thoraco-abdominal aortic disease for pre-operative planning of endovascular treatment: thus the data set required for our analysis of spinal cord vascular anatomy is already available. This paper provides examples of the SC vasculature imaging that can be obtained with 64 row scanners and appropriate postprocessing.

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Knowledge of the spinal cord (SC) blood supply is intuitively important when treating patients with thoracic and thoraco-abdominal aortic diseases. Unfortunately, the SC vasculature is complex and difficult to study because it consists of very small vessels (e.g., radicular arteries and anterior spinal artery (ASA), 0.2–0.8 mm; posterolateral

spinal artery 0.1–0.4 mm; and arteria radicularis magna (ARM) 0.5–1.2 mm) running in intricate, three-dimensional planes with substantial regional and inter-individual variability. Most of our anatomical fundamental knowledge of the SC circulation derives from microinjections of different staining fluids and micro-radiological studies in post-mortem specimens.¹ A very useful source of insight on normal and pathological vascular anatomy of the SC is offered in an elegant treatise by Armin K. Thron.¹

Recently, computerised tomography (CT) and magnetic resonance (MR) have extended the ability to provide non-invasive evaluation of the SC vasculature of individual

* Corresponding author at: G. Melissano, Chirurgia Vascolare, IRCCS H. San Raffaele, Via Olgettina 60, 20132 Milan, Italy. Tel.: +39 02 2643 7130; fax: +39 02 2643 7148.

E-mail address: g.melissano@hsr.it (G. Melissano).

patients. The ability of CT and MR to detect the artery of Adamkiewicz was recently analysed in a review including 1196 patients.² In particular, CT angiography offers excellent imaging capabilities, and it is widely used for diagnosis and therapeutic planning of thoracic and thoraco-abdominal diseases. Thus, for the study of SC anatomy in patients with aortic disease, the data set, that is needed is usually already available.

All the CT reconstructions presented in this study were obtained using Osirix and Fovia, Inc., High Definition Volume Rendering plug-in.³ All the artworks were originally produced by one of the Authors (F.C.).

Impressively, accurate anatomical descriptions were provided as early as 1881 by Adamkiewicz and Kady, among others.^{4,5} They used a clearing method with clove oil (mentioned by Virchow in 1857) that renders tissue sections transparent so that the stained vessels can be followed under the microscope. They described the vascular supply of the SC as one anterior and two posterolateral anastomotic trunks running longitudinally (Fig. 1).

Arteries directly supplying the SC (intrinsic arterial system) are divided into: (1) a central (centrifugal) system

fed by the sulcal arteries and (2) a peripheral (centripetal) system, the pial plexus (or pial network), which gives rise to perforating branches (Fig. 2). The pial network covers the SC along its entire length and forms an impressive secondary anastomotic system between the anterior and posterolateral longitudinal vessels. Intraparenchymal anastomoses have rarely been demonstrated.

The intercostal arteries divide 3 times before reaching the ASA, the crucial vessel supplying blood to the spinal grey matter:

- 1) The first branch of the intercostal artery is the nervo-medullary artery.
- 2) The latter divides into an anterior and a posterior radicular artery.
- 3) The anterior radicular artery divides into a descending and an ascending branch.

The ASA is basically an anastomotic channel between ascending and descending branches of neighbouring anterior radicular arteries.

This branching pattern is schematically depicted in Fig. 3, which shows the images of these arteries obtained with different rendering tools from actual patients' CT data sets.

It is noteworthy that the nervo-medullary artery division is a steady supplying vessel of the anterior and posterior parts of the vertebral canal, the nerve roots and the dura; however, only at certain levels do the anterior and posterior radicular arteries cross the dura together with the anterior and posterior nerve roots to reach the surface of the medulla. Phylogenetic embryological studies have shown that by the 16th week, the development of the ASA

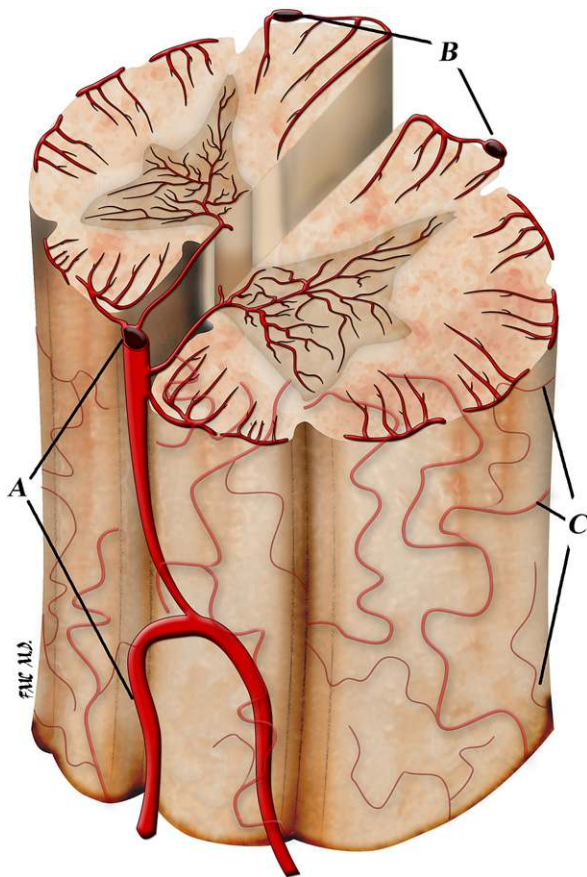


Figure 1 The SC is covered by a net-like anastomosing vascular system in which the ASA (A) and the two posterolateral spinal arteries (B) can be considered the most constant longitudinal anastomotic trunks. The pial network (C) and intra-medullary anastomoses may only be important for slower circulatory adjustments.

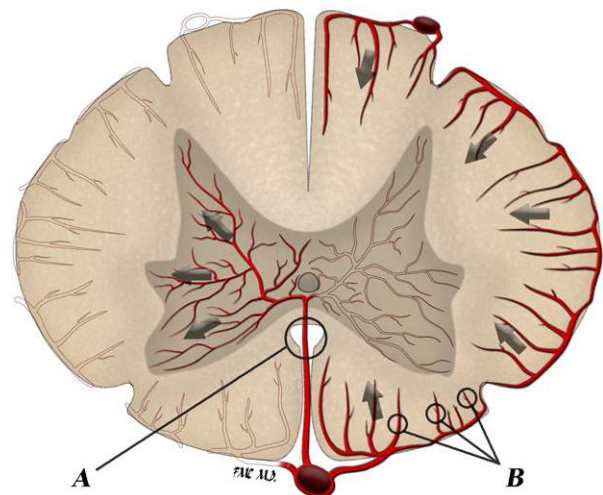


Figure 2 The intrinsic arterial system of the SC. The central system (left side) is represented by the sulcal arteries (A), which penetrate in the medulla and branch tree-like mainly in the grey matter. The peripheral system (right side) consists of numerous small arteries denominated "Rami perforantes" (B) which originate in the pial network and pass through the white matter in a radial course.

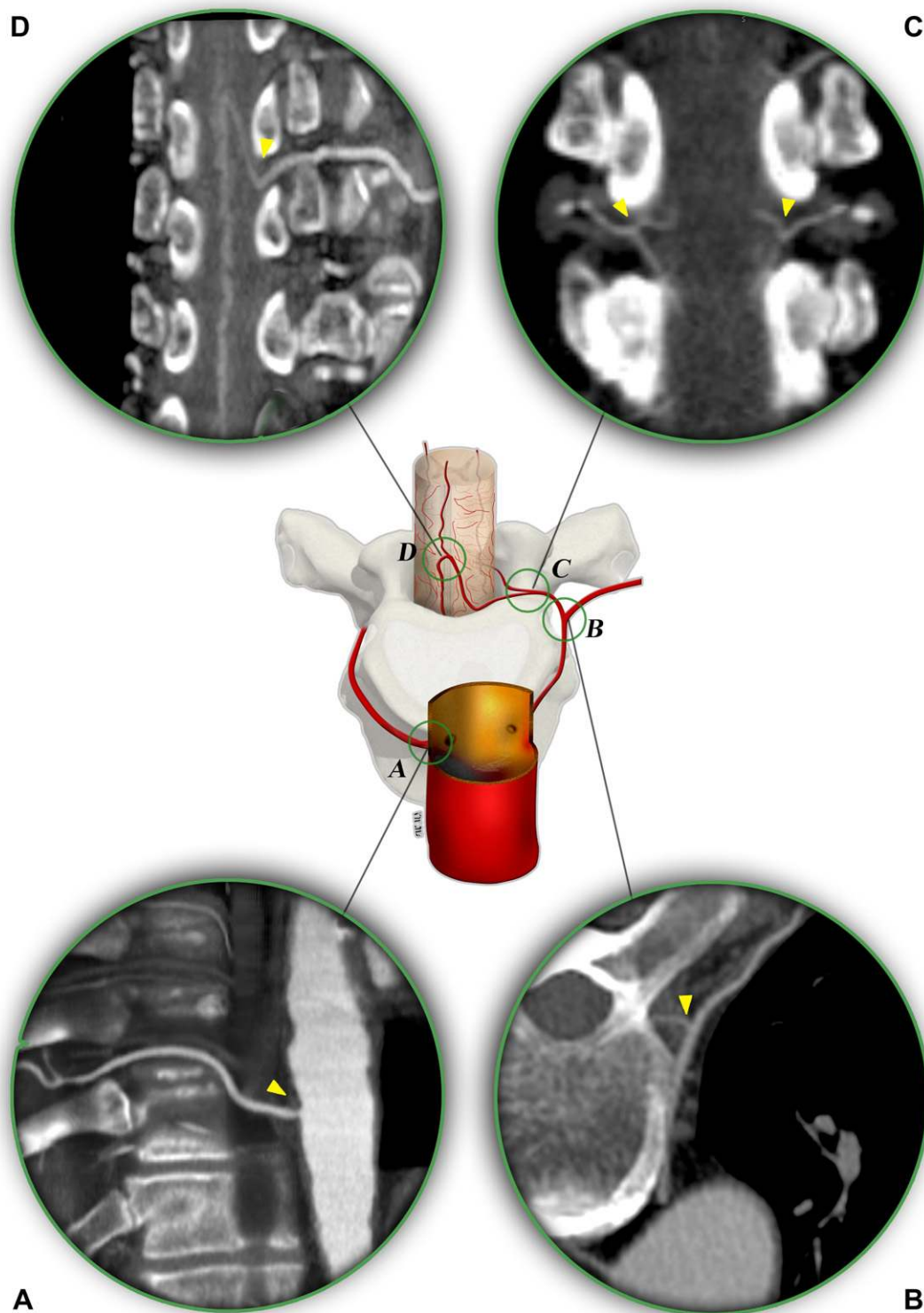


Figure 3 Schematic depiction of the SC extrinsic arterial system. (A) Origin of the intercostal arteries from the aorta [insert: CT Curved Multi Planar Reconstruction (MPR)]. (B) Origin of the nervo-medullary artery (or radiculo-medullary artery) from the intercostal artery [insert: CT Maximum Intensity Projection (MIP) of an axial view]. (C) The nervo-medullary artery divides into constant branches, the anterior and posterior radicular artery [insert: CT MIP of a coronal view]. (D) One anterior radicular artery is always dominant in calibre in the thoracic region and is therefore called the ARM (or the artery of Adamkiewicz) [insert: CT curved MPR].

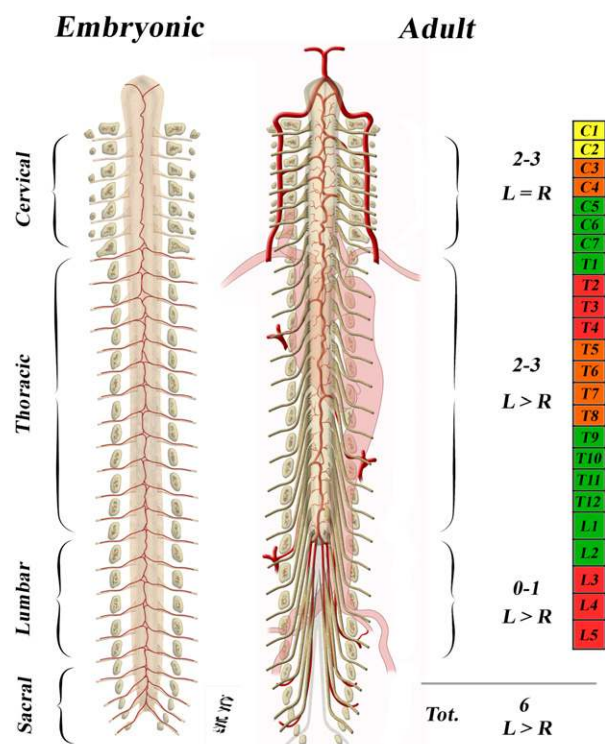


Figure 4 Embryonic stage (16th week) of the ASA from 31 bilateral segmental feeders. The ASA develops from the anastomosis of ascending and descending branches of each segmental anterior radicular artery. In the adult, most of the segmental feeders of ASA regress. Only a few are left in the adult. A mean of 2–3 at the cervical level (left = right), 2–3 at the thoracic level (left > right) and 0–1 at the lumbosacral level (left > right). The differences of the vaso-afference in the vertebral regions are depicted in different colors (obligatory = green, deficiency = red, facultative = orange, and variable = yellow).

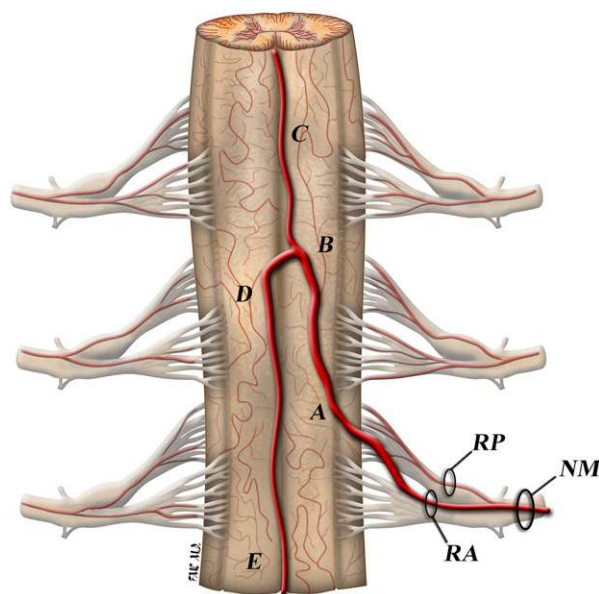


Figure 5 Schematic view of the ARM. The nervo-medullary (NM) artery divides into an anterior (RA) and posterior radicular (RP) artery. Only a few radicular arteries cross the dura and feed directly into the ASA. (A) ARM division, (B) branching of ARM, (C) smaller ascending branch, (D) typical “hairpin” curve (E) larger descending branch.

is followed by regression of most of the original 31 bilateral segmental feeders.¹ In fact, only a few of these segmental branches are left in the adult (Fig. 4).

In the thoraco-lumbar region one (occasionally two or three) anterior radicular artery (the artery of Adamkiewicz) is always distinctly dominant in calibre and is therefore called the great radicular artery or ARM.¹ Division of the ARM is anatomically very characteristic (Figs. 5 and 6): the

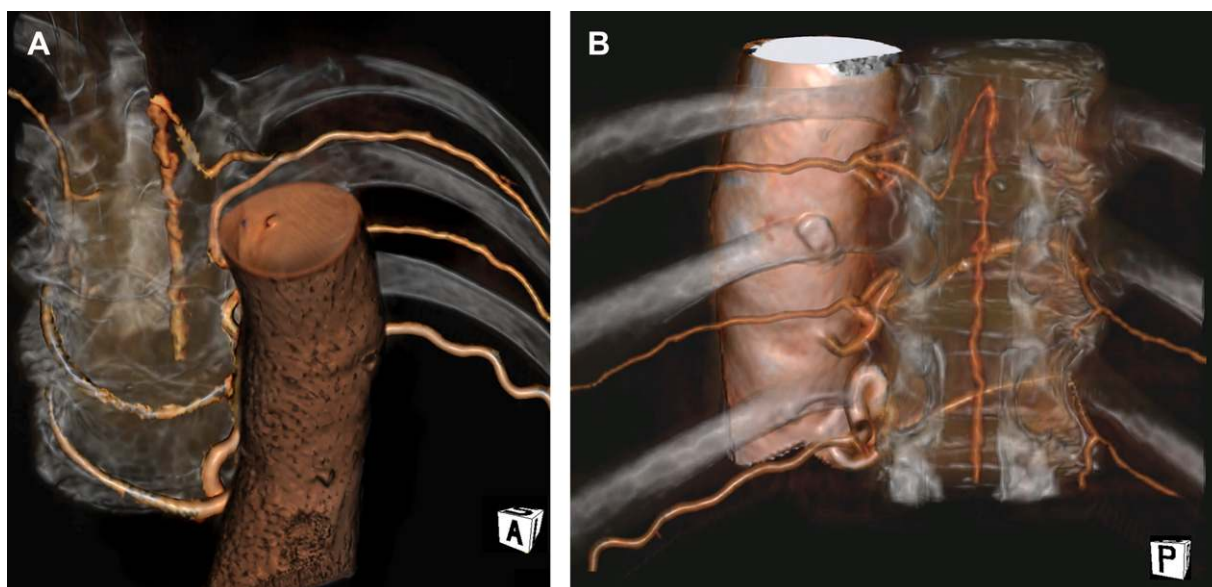


Figure 6 CT 3D volume rendering of SC in (A) antero-lateral view and (B) posterior view.

radicular artery has a steep cranially directed course in the thoraco-lumbar region owing to the ontogenetical 'ascension' of the SC. Branching takes place lateral to the midline, a smaller ascending branch is issued before reaching the midline and the main artery continues its vertical course, bending sharply in a typical 'hairpin' curve into the descending branch. In the upper thoracic region, branching is more often T shaped. In the cervical region, the ASA continuity is less constant and sometimes there is duplication. The course of the ASA often deviates in a zigzag from the midline and varies in calibre, with typical narrowing.

Knowing the principal anatomical features of SC blood supply of individual patients undergoing thoraco-abdominal interventions, whether open or endovascular, has several potential benefits. For open surgery, analysis of the SC vasculature could show the aortic region feeding the ARM that requires re-implantation. For endovascular procedures, it could show whether the intercostal artery supplying the ARM will be covered by the stent graft and avoid unnecessary coverage. It can also be used to stratify patients according to the risk of ischaemic SC events, possibly guiding the selective use of cerebrospinal fluid

(CSF) drainage and left subclavian and hypogastric artery revascularisation.

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None.

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