25 Preoperative Assessment of the Spinal Cord Vasculature

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25.1 Introduction

Spinal cord ischemia is a rare and devastating complication of aortic aneurysm repair that has a great impact on quality of life and surgical success. Given the difficulty in predicting paraplegia in patients with aortic pathologies, new strategies are being studied to prevent spinal cord injury after aortic surgery.

Surgical repair of thoracoabdominal aneurysms was first described in 1955, and, despite improvements, the risk of spinal cord ischemia remained substantial, between 4% and 11%, with a mortality risk ranging from 3% to 17%, even at centers with extensive experience [1–3]. Therefore, the search for a better treatment option is still ongoing**.** One such improvement was the development of thoracic endovascular aortic repair (TEVAR). Because the technique does not require aortic cross-clamping, has shorter surgery times, and involves less invasive procedures, it lowered the incidence of spinal cord ischemia to 1–5% [4–7], a rate that is nevertheless high.

Understanding the spinal cord (SC) vascular supply is key when treating patients with aortic diseases; however, the SC vasculature is complex and difficult to study because it consists of very small vessels running in intricate, three-dimensional planes with highly variable anatomy [8]. Current noninvasive imaging techniques can identify the artery of Adamkiewicz (AKA, also known as arteria radicularis magna) and show spinal cord vasculature; however, their sensitivity and specificity are insufficient, with several factors affecting their detection capability [9, 10]. Conversely, angiography, formerly considered the gold standard method, is too invasive for current clinical routine use, hence the need for post-processing of images using three-dimensional multiplanar reconstruction to enhance detection of critical closure sites.

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25.2 Anatomy

Blood supply to the medulla comes from the intercostal and lumbar arteries, which split three times before reaching the spinal cord, and from the subclavian and hypogastric branches. Except for the hypogastric arteries, which originate from the iliac arteries, the others arise from the aorta. After the first branch, the spinal branch, which

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divides into anterior and posterior radicular arteries, the intercostal artery bifurcates into the dorsal and vertebral branches. Only at some spinal levels do the anterior and posterior radicular arteries penetrate the dura mater, reaching the spinal cord. Only some of the original segmental branches persist into adulthood (2–14, mean = 6). The anterior spinal artery (ASA), which is a key component of the vascularization of the spinal cord and anterior and lateral funiculi, is basically an anastomotic channel between the ascending and descending branches of neighboring anterior radicular arteries (Fig. 25.1) [11]. The last bifurcation of the spinal branch provides a constant supply of oxygenated blood to the anterior and posterior spinal cord, nerve roots, and dura mater.

Generally, the largest of the anterior radicular arteries, with its characteristic "hairpin" shape, is referred to as the great anterior radicular artery or artery of Adamkiewicz (AKA) (Fig. 25.2) [11].

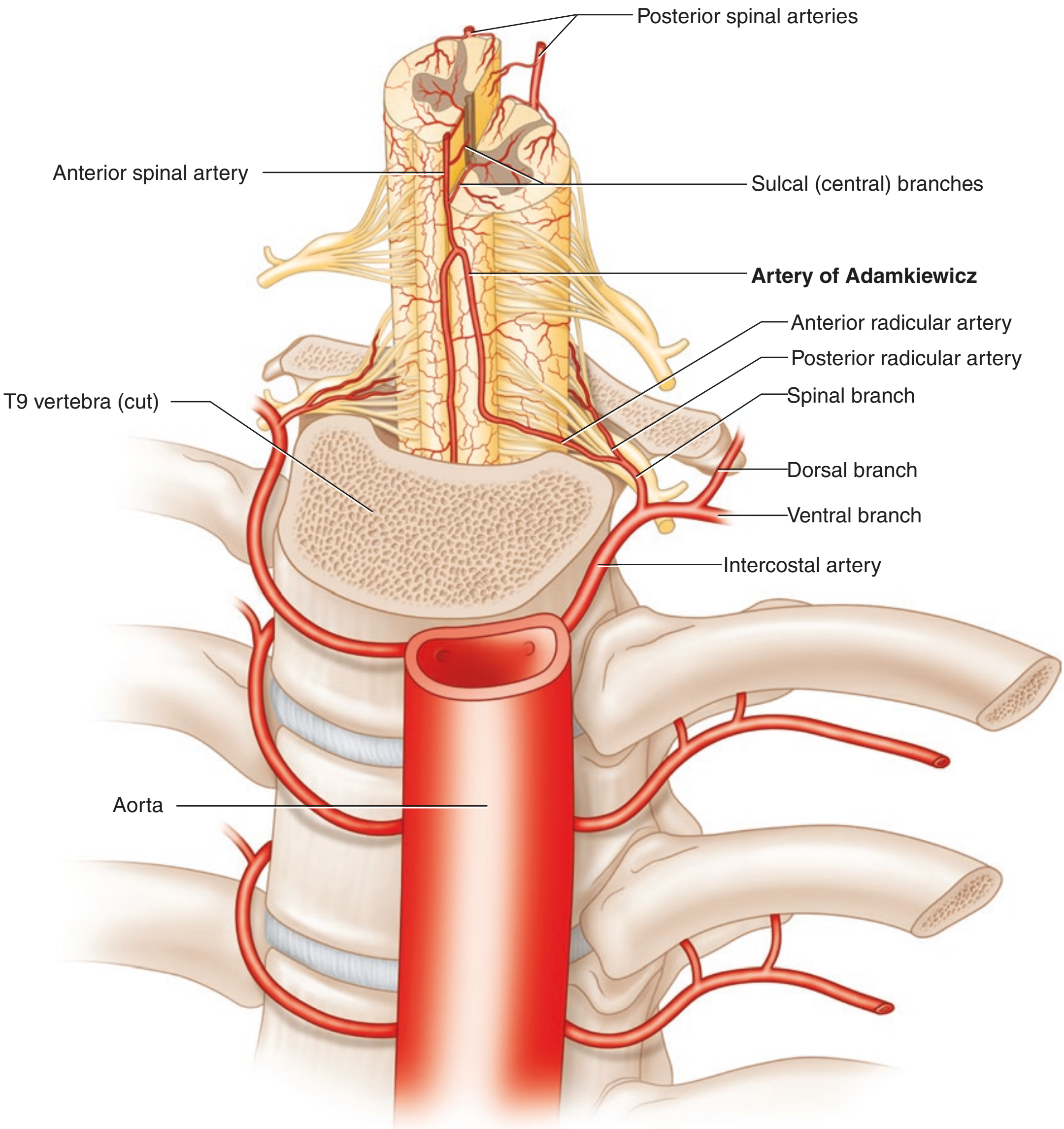

Fig. 25.1 Schematic drawing of the blood supply to the spinal cord [11]

The posterior radicular artery follows a pattern similar to the anterior radicular artery but gives rise to two longitudinal anastomotic channels, the posterolateral spinal arteries. Arteries that supply the spinal cord are divided into a central system supplied by the sulcal arteries and a peripheral system, the pial plexus, from which the perforating branches originate (Fig. 25.2) [8, 12–14]. The AKA usually originates from a left posterior intercostal artery at the levels of T9–T12 (Fig. 25.6) [9].

The venous drainage of the spinal cord is no less controversial and characterized mainly by the great posterior radicular vein, identified by its “coat hook” appearance, the posterior spinal vein, and the anterior spinal vein [27]. The anatomic significance of venous drainage preoperative planning of aortic surgery lies in its differentiation, in the image exams, from the arterial system (Fig. 25.3). Posteriorly, there is just one posterior spinal vein, as opposed to two posterolateral arteries, which is often larger than the anterior median vein [28].

Even though there is a single identifiable artery supplying the spinal cord at the thoracic level, it is not the only source of medullary blood supply. Griepp et al. refined the anatomic conceptualization of the collateral circulation network for spinal cord blood supply [29] (Fig. 25.4), providing details of its vascular redundancy. There is an axial network of small arteries in the spinal canal, paravertebral tissues, and paraspinal muscles that anastomose with each other and with the nutrient arteries of the spinal cord. Inputs

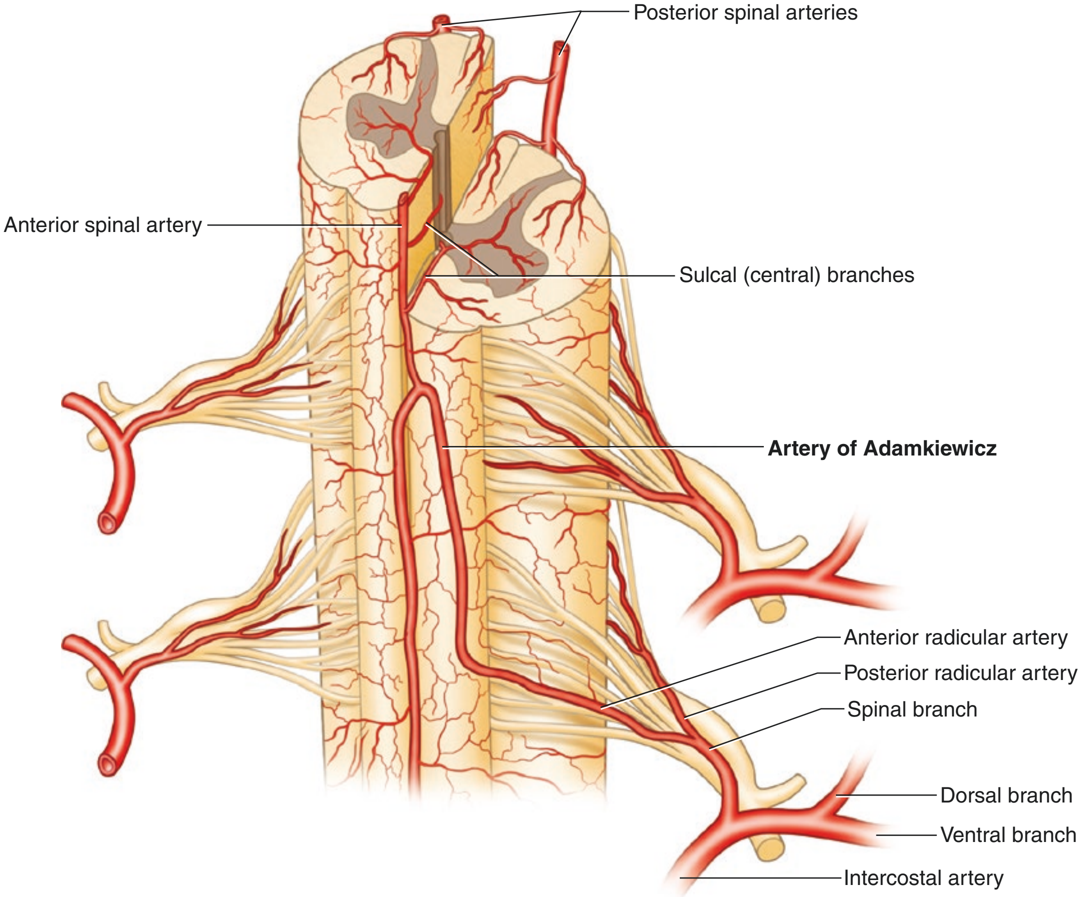

Fig. 25.2 Spinal arterial anatomy showing the artery of Adamkiewicz [11]

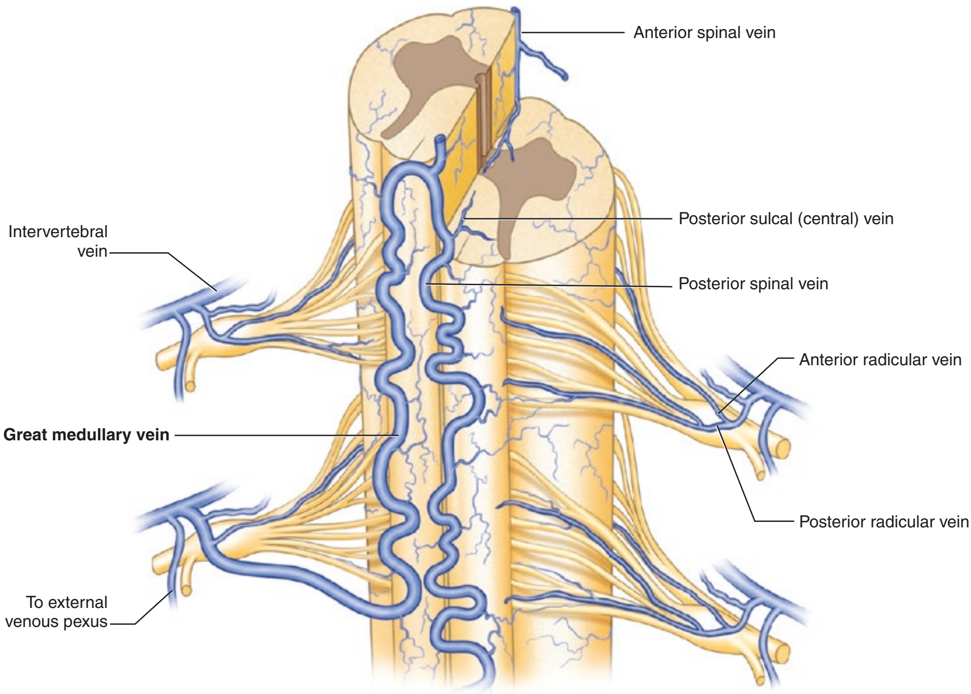

Fig. 25.3 Spinal venous anatomy [11]

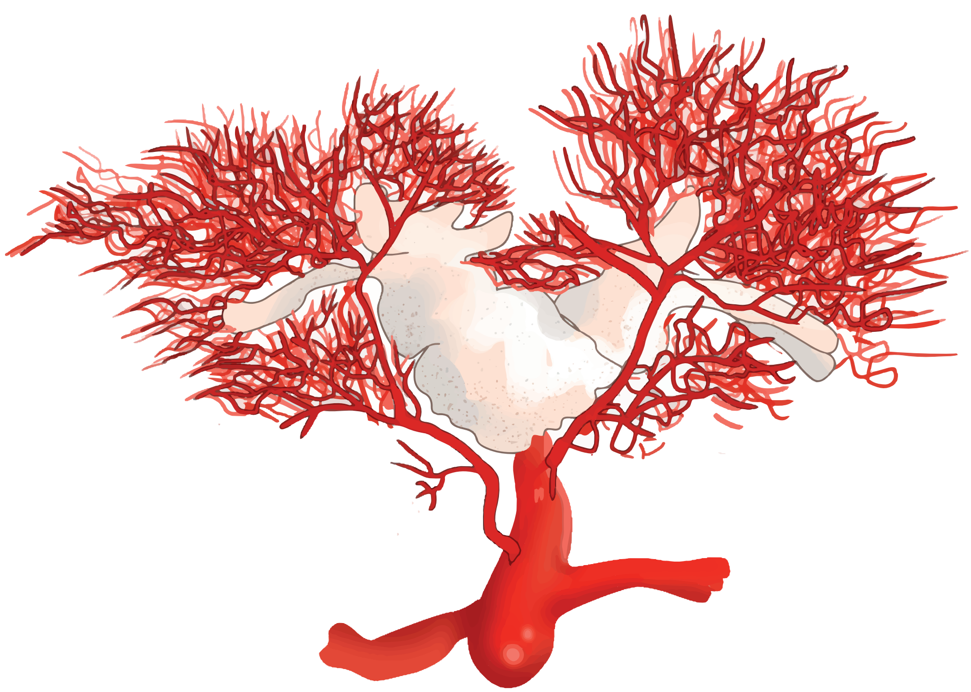

Fig. 25.4 The aorta is seen giving off segmental arteries which course around the vertebral body to supply the paraspinal muscles and, in the midline, the anterior spinal artery. The image shows the extensive anastomotic network for spinal cord blood supply

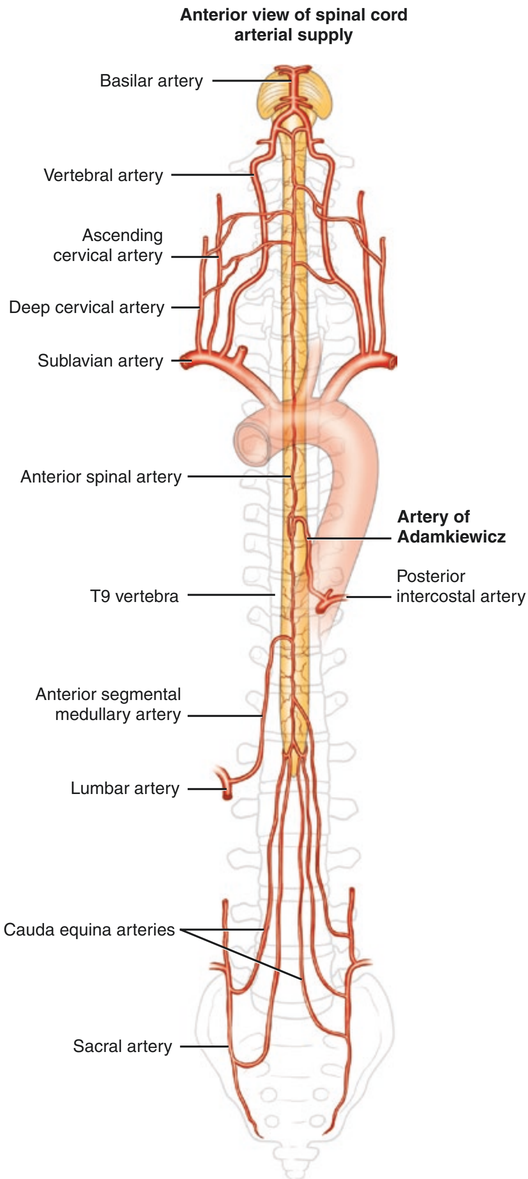

Fig. 25.5 Network of collateral vessels: subclavian, hypogastric, intercostal, and lumbar arteries

into this network include the segmental vessels (intercostal and lumbar arteries), subclavian arteries, hypogastric arteries, and their branches (Fig. 25.5) [30, 31]. In addition to these multiple inputs, there is also an extensive network of epidural arterial and small vessels that supply the paraspinal musculature (Fig. 25.4). All these vessels are interconnected and have anastomoses with the subclavian arteries, cranially, and the hypogastric arteries, caudally [31].

This network of collateral vessels can provide compensatory flow to the spinal cord in the event of occlusion of large caliber vessels [31] and increase cord nutrient flow from one source when another is reduced. Conversely, flow can be decreased if an alternate low resistance pathway is opened, such as when arterial steal occurs [29]. According to Adamkiewicz's partial flow theory, the bloodstreams of the radicular arteries reach the medullary surface in two streams, one running cranially and one caudally [13].

25.3 Imaging Acquisition Techniques

The importance of identifying and localizing the artery of Adamkiewicz prior to thoracic and thoracoabdominal surgery to prevent spinal cord injury was demonstrated by Kieffer et al. in the 1980s [32] using angiography. Arterial and posterior radicular arteries and spinal artery branches with calibers greater than 200–400 μm have been demonstrated angiographically [13]; however, this procedure is invasive, and its risks, including the risk of embolization [33], are currently considered unacceptable [34].

Computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are minimally invasive imaging techniques currently used to assess spinal cord blood supply [28]. There is growing evidence that the artery of Adamkiewicz can be identified by these noninvasive techniques [15–21, 33, 35–40]. AKA detection rates range from 67% to 100% with MRA [28]; however, this imaging technique is not routinely used for the preoperative assessment of patients with aortic diseases. Conversely, CTA is performed routinely, but AKA detection rates vary widely from 18% to 100% [28] depending on post-processing technique, type of scanner, and operator experience. In addition, atherosclerotic disease and atherosclerotic risk factors may hinder SC blood supply visualization [9]. AKA identification rates are higher in studies using multiple detection techniques [18, 19, 41] (Fig. 25.6).

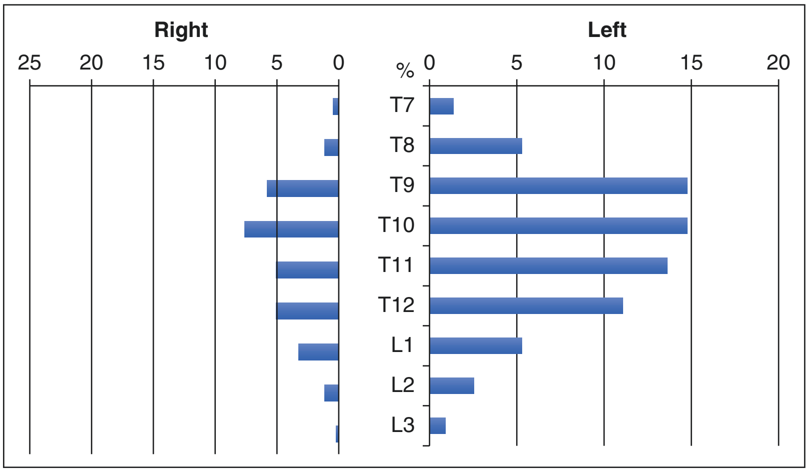

Fig. 25.6 Frequency distribution of the side of origin in studies that used computed tomography angiography for AKA identification [9, 15–26]

Even though magnetic resonance does not involve exposure to ionizing radiation and has a small risk for complications [28], it is not tolerated by all patients due to the long scan times [42]. The ability to discriminate between arterial supply and venous drainage is a clear advantage of MRA, while the proximity to skeletal structures is irrelevant, but special acquisition protocols, particularly fast acquisition techniques that use a strong bolus, in addition to good skill and dedication in image post-processing, are required for optimal results [28].

25.4 Influence of Artery Detection or Presence of Artery on Postoperative Spinal Cord Ischemia

A retrospective study using a risk model for the analysis of a database with 2235 patients from 19 European centers revealed 38 (1.7%) cases of symptomatic spinal cord ischemia. This study indicated that endovascular closure of intercostal arteries combined with occlusion of collateral vessels supplying the spinal cord is a risk factor for symptomatic spinal cord ischemia. The mathematical algorithm employed identified that intraoperative hypotension and simultaneous closure of at least two spinal cord vascular territories were relevant in the development of ischemia and that extensive coverage of intercostal arteries alone is not associated with symptomatic spinal cord ischemia [30]. Also, Murakami et al. suggested that the AKA is not the only source of SC blood supply [43]. Nevertheless, retrospective analysis of 457 patients and their in-hospital complications revealed that paraplegia and paraparesis were significantly associated with a length of the covered aorta >20 cm [44], which supports the importance of segmental arteries for SC blood supply. Yingbin et al. demonstrated the importance of identifying the AKA for selecting long endografts in cases of thoracic aortic dissection [45].

The mechanism of spinal cord ischemia after thoracic endovascular aortic repair (TEVAR) has not been fully clarified and appears to be multifactorial [3, 33]. Spinal cord perfusion depends on the gradient between arterial pressure and cerebrospinal fluid pressure [33].

25.5 Spinal Cord Visualization Technique

For AKA visualization [9, 21, 46], axial images are scrolled over at a large magnification and examined for the presence of two enhanced spots in the spinal cord, corresponding to the ASA and AKA, while tracing their cranial-caudal trajectory. Next, three-dimensional multiplanar reconstruction is used, enabling the simultaneous visualization, in three windows,

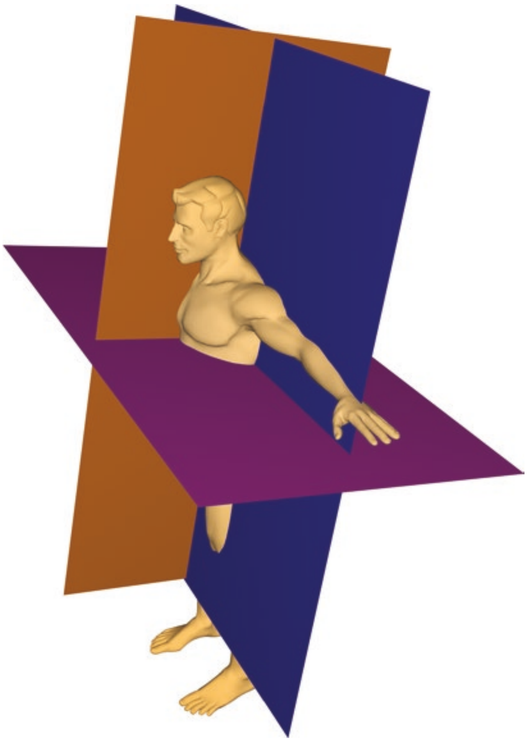

Fig. 25.7 Oblique planes used for AKA localization on three-dimensional multiplanar reconstruction

of three oblique planes at 90° in relation to each other (Fig. 25.7). The entire spinal cord can be visualized by moving the crosshair. A video illustrating the technique is available at http://vascular.cc/aka.html, and an AKA identification prediction model can be seen here https://vascular.pro/aka-model.

The crosshair is placed on the spinal cord at the level of the last thoracic vertebrae, and a sagittal view is displayed in the upper left window. By adjusting the position and angle of the crosshair to cover most of the spinal cord longitudinally in the upper left window and adjusting slice thickness using the maximum intensity projection (MIP) algorithm and "windowing" (apparent Hounsfield scale), an oblique coronal or paracoronal view of the spinal cord is produced in the large window. Tilting the crosshair and scrolling over the images along the anteroposterior direction allows a quick exploration of the entire spinal cord (Fig. 25.9) [21].

The ASA is identified, in the anterior aspect of the spinal cord, as a thin longitudinal vessel (Fig. 25.8a), whereas the AKA is readily identified by its "hairpin" appearance, supplying the

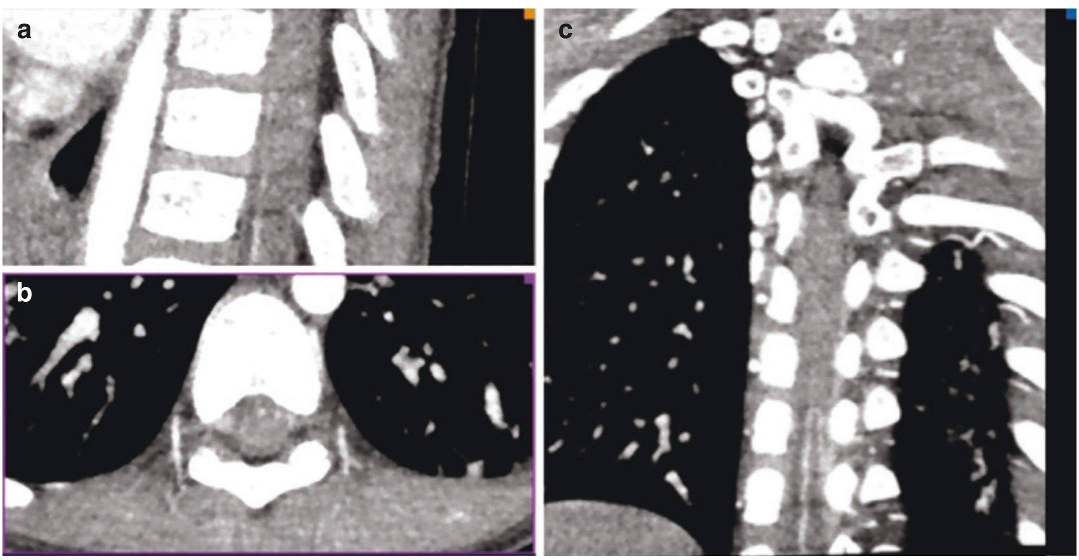

Fig. 25.8 *OsiriX* software window. The green arrow shows the ASA, and the red arrow shows the AKA. (**a**) Sagittal view. (**b**) Axial view. (**c**) Coronal oblique view

anterior spinal artery, in a paracoronal view using two-dimensional multiplanar reconstruction (MPR) (Figs. 25.8c and 25.9).

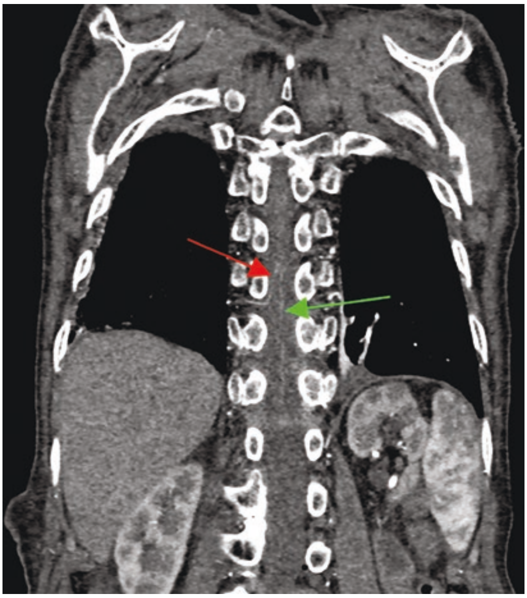

Fig. 25.9 Three-dimensional MPR oblique view showing the AKA (red arrow) with its typical "hairpin" appearance and the ASA (green arrow)

The identification of the AKA and ASA is based on the following criteria:

- Continuity of the AKA traceable to vessels of known arterial nature such as the intercostal artery or aorta (Fig. 25.10) [16, 19, 20, 36]. Continuity with arteries is certainly a highly relevant factor; however, this is not always achieved and other criteria are needed [16, 19, 20, 28, 36].
- Simultaneous identification of the AKA and ASA as two enhanced spots in the ventral aspect of the spinal cord on consecutive axial scans [19, 20, 28].
- Characteristic anatomic relationship of the two vessels, i.e., "hairpin" shape (Fig. 25.3) [19].
- Failure of venous enhancement and visualization of the posterior spinal vein and other veins surrounding the spinal column (intercostal, lumbar, and azygos veins) [28].

The AKA can be identified with computed tomography angiography in approximately 70% of cases [9, 17–20, 26, 27, 38, 41, 47–50], and this imaging modality is routinely used in the

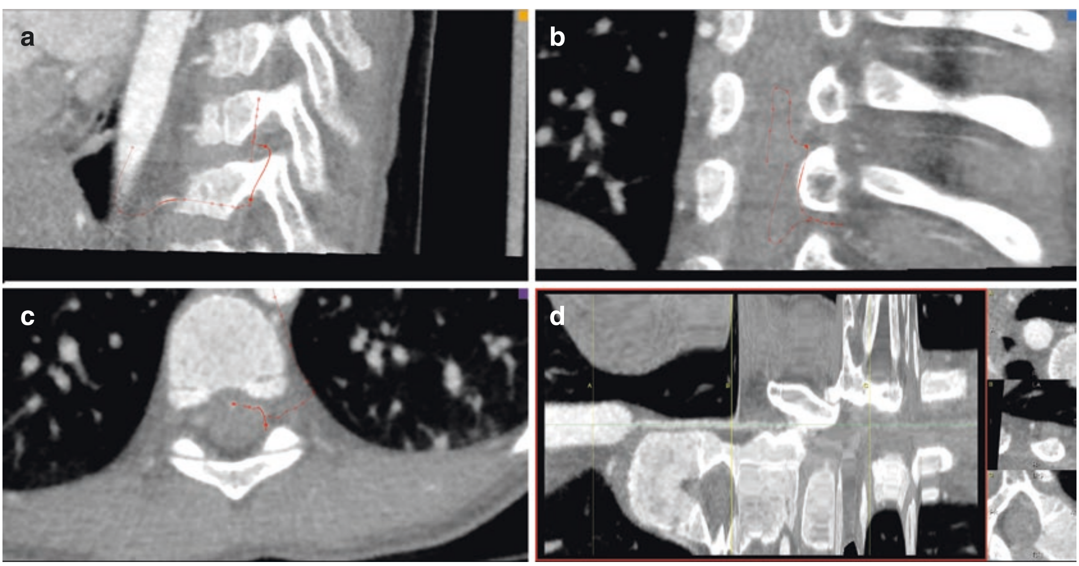

Fig. 25.10 (**a**–**c**) Oblique views showing the three-dimensional path of the AKA. (**d**) Continuity of the AKA (red arrow) from the aorta (yellow arrow) through the intercostal artery (blue arrow) and ASA (green arrow) on three-dimensional curved multiplanar reconstruction, which reconstructs the course of the vessel from its origin in the aorta through the spinal cord

preoperative assessment of thoracoabdominal aortic aneurysms. The imaging acquisition protocol for SC blood supply visualization is similar to standard angio-CT protocols used in most centers.

25.6 Conclusion

When the risk of intraoperative closure of two vascular territories supplying the spinal cord [30] is identified in the presurgical planning of aortic aneurysm repair, AKA disruption—or at least that of collateral vessels—can be prevented with prior knowledge of its location using the method described here.

If the AKA identification method proposed cannot be applied to a patient, the surgical team should then rely on anatomic studies [9] that show the existence of a critical area of great importance for SC circulation between the levels of T9 and T12. This area requires special attention from the surgeon to preserve the AKA as well as if possible the other spinal cord blood supply sources.

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