Detection of the Adamkiewicz artery in computed tomography of the thorax and abdomen

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Abstract

Background. The great anterior radiculomedullary artery, also known as the artery of Adamkiewicz (AKA), is a small-caliber vessel which arises from the intercostal or lumbar arteries branching out from the aorta.

Objectives. The aim of this study was to evaluate detection of the AKA, as well as its level and side of origin, with multi-slice contrast enhanced computed tomography (MSCT) of the abdomen and thorax performed during everyday clinical practice, and to compare the results with the literature.

Material and methods. The study retrospectively evaluated 200 consecutive MSCT images of the thoracic and thoracoabdominal aorta performed at Wroclaw Medical University's Department of General and Interventional Radiology and Neuroradiology as part of normal clinical work-ups. The CT examinations were performed with a 64-slice CT scanner. Arterial-phase images were analyzed for detection of the AKA and for anatomical variants of the AKA.

Results. Recognition of the AKA was achieved in 43 of 200 patients (21.5%). Out of these 43 cases, the AKA originated on the left side in 36 instances (83.7%) — a significantly higher number than on the right side (only in 6 cases, 14%); in one case (2.3%) it arose from both sides (p < 0.05, T-test). Most of the AKAs (24 cases, 55.8%) originated on the left side at level T11 or T12. In 13 patients (30.2%) the AKA arose from T11 or from T12 intercostal arteries. The origin of the AKA varied greatly and ranged from T5 (2.3%) to L2 (2.3%).

Conclusions. The AKA is characterized by left-side lateralization and is associated with a wide range of origin, from T5 to L2. Detection of the AKA is, relatively speaking, rarely possible in routine clinical CT in the arterial phase — only in 1/5 of the patients. Therefore it is necessary to perform dedicated, individual arterial phase bolus tracking enhancement CT scans from the T5 to L3 level.

Key words: Adamkiewicz artery (AKA), computed tomograpy (CT), great anterior radiculomedullary artery

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The great anterior radiculomedullary artery was first described in 1892 by Albert Adamkiewicz. The most important of Adamkiewicz's discoveries included the histology of neuronal tissue and the vasculature of the spinal cord. The description of the spinal arterial network known as the vascular crown (or "vasocorona") is also a result of his research on bidirectional blood flow along the arterial system of the spinal cord. The zone that covers the anterior 2/3 of the spinal cord in the thoracolumbar segment is supplied with blood through the artery of Adamkiewicz (AKA). The AKA is a small vessel with a diameter of 0.6–1.2 mm starting from the posterior part of the segmental arteries (intercostal or lumbar arteries), which are subdivided into the radiculomedullary artery, the muscular branch and the dorsal branch. The radiculomedullary artery divides into the main anterior branch (the AKA) and the small posterior branch. The length of this artery is estimated to be about 2.5 cm measured from the dura mater to the spinal cord, and about 15 cm in its downward course.² The AKA courses through the rostral or midportion of the intervertebral foramen and is typically situated ventrally to the dorsal root ganglion (ventral ramus). Then it travels with the ventral root to the ventral surface of the spinal cord. Within the foramen and in the perispinal region the artery divides into from one to five small branches. When the AKA meets the anteriorspinal artery (ASA), it takes an acute turn caudally and directs most of its blood flow downwards (Fig. 1, 2).³⁻⁵

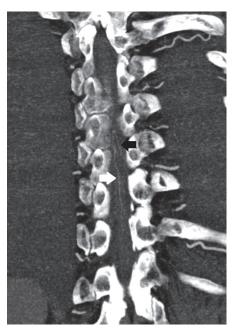


Fig. 1. Contrast-enhanced CT, oblique MIP reconstruction. AKA left-side origin T9. Characteristic "hairpin turn" connection between the AKA (black arrow) and ASA (white arrow) in a 61-year-old male patient

Preoperative anatomical evaluation of the AKA is essential in many clinical disciplines: vascular surgery (aortic aneurysms), neurosurgery (intramedullary tumors), as well as urology and pediatric surgery (retroperitoneal



Fig. 2. Contrast-enhanced CT, oblique MIP reconstruction. AKA originating from the left L2 lumbar artery (white arrow) in a 56-year-old male patient. Both the ascending and major descending branches of the ASA are seen (small arrows)

dissections), because it helps avoid serious neurological complications such as paraplegia or paraparesis.^{1,2}

The aim of this study was to evaluate the detection of the AKA, as well as its level and the side of origin, with multi-detector contrast enhanced computed tomography (MDCT) of the abdomen and thorax performed during everyday clinical practice, and to compare the results with the literature.

Material and methods

The study reviewed 217 consecutive CT images of the thorax and abdomen performed at Wroclaw Medical University's Department of General and Interventional Radiology and Neuroradiology as part of everyday clinical work-ups in 2011-2013. The patients (119 women, 98 men) aged 8-86 years (mean age 62 years) underwent helical CTs of the thorax and abdomen due to various medical indications (128 oncological patients, 46 trauma patients and 26 inflammatory processes). Fourteen patients with symptoms of spinal claudication and suspected spinal infarction were excluded, as well as three with paravertebral masses. The examinations were performed with a 64-detector CT scanner LightSpeed VCT (GE Healthcare, Milwaukee, USA). The scanning covered an area from the top of the thorax to the pubic symphysis. The detector thickness was 0.625 mm, the pitch was 1.3 and the average gantry rotation time was 0.6 s. The tube voltage was 120 kV and all the scans were obtained using fully automated anatomy-based dose regulation modulating the effective tube current from 100 to 650 mA. The signal-tonoise ratio (SNR) ranged from 14 to 21. The contrast bolus



Fig. 3. Contrast-enhanced CT, oblique MIP reconstruction. AKA originating from the right T9 lumbar artery (white arrow) in a 76-year-old female patient. The foramen section of the AKA is not clearly visible because of bone-related artifacts

Table 1. The criteria for identification of the Adamkiewicz artery in MDCT: at least 3 major criteria and 2 minor criteria for each observer

Major criteria

the presence of a characteristic "hairpin turn" connection between the AKA and ASA (Fig. 1)

arterial continuity between the aorta and the ASA

reduced enhancement of the vessel in the second phase of contrastenhanced CT

origin between T7-L2

Minor criteria

diameter 0.6-1.2 mm

origin between T9-12

straight intradural trajectory

AKA - Adamkiewicz artery; ASA - anterior spinal artery.

was administered with an automatic syringe. Vascular access was achieved by inserting an 18G or 20G plastic intravenous catheter into the cubital basilic or cephalic veins at forearm or wrist level. The volume of highly-iodinated contrast medium (350-370 mg iodine/mL) ranged from 80 to 140 mL, depending on the patient's body weight. The contrast was administered at a flow rate of 3.5 mL/s, followed by 40 mL of saline as a wash-out bolus. Scanning always began 30 s after the start of contrast administration to match the arterial phase. The overall scanning time was 5-8 s, depending on the area covered by the scan. The obtained images were analyzed using a dedicated workstation (Advantage Windows Workstation 4.4, GE Healthcare, Milwaukee, USA). Multiplanar reconstructions (MPR) and maximum intensity projection (MIP) images were used, including axial, oblique and coronal planes (Figs. 1-6). Window and level settings were selected to maximize arterial-to-background discrimination. Aortic enhancement at the T12 level was from 128 to 357 HU (mean 223 HU). The iodine dose was 530 mg I/kg.

The criteria for detection of the AKA are presented in Table 1. The detection and origin of the AKA were evaluated according to the criteria listed in this table by two independent radiologists (MG and MB) with 10 and 4 years' experience in CT, respectively. The anatomical origin of the AKA was defined as the level of the vertebral body with the intervertebral foramen underneath, through which the segmental artery (SA) of the aorta entered the spinal canal and continued as the Adamkiewicz artery.

Results

In evaluations of 200 routine MDCT examinations of the abdomen and thorax, recognition of the AKA was achieved in 43 patients (21.5%, 13 women and 30 men, aged 26–90 years, mean age 62 years). The AKA originated from the left side in 36 cases (83.7%), in 6 (14%) from the right side and in 1 case (2.3%) from both sides. In general, the AKA was visualized in 84.1% of cases on the left side and in 15.9% on the right side.

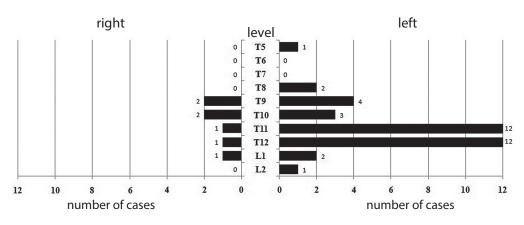


Fig. 4. AKA origin and level in relation to the posterior intercostal or lumbar artery. Note the high left T9-12 prevalence

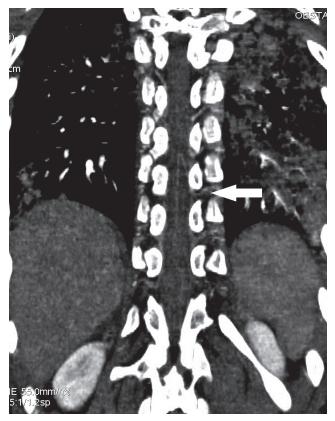


Fig. 5. Contrast-enhanced CT, oblique MIP reconstruction. The artery of Adamkiewicz is typically located in the upper half of the foramen (white arrow)

Most AKAs (24 cases, 55.8%) began on the left side at the level of either T11 or T12. In 13 patients (30.2%) the AKA originated from the T11 posterior intercostal artery. In another 13 patients the AKA originated from the T12 posterior intercostal artery. The origin of the AKA varied greatly and ranged from T5 in one patient (2.3%) to L2, likewise in 1 patient (2.3%) (Fig. 2). The remaining levels were T9 in 6 patients (14.0%) (Fig. 1); T10 in 5 cases (11.6%); L1 in 3 patients (7.0%); and T8 in 2 patients (4.7%). The extreme upper and lower points and T8 level showed only left-sided AKAs, whereas at the rest of the levels there were also right-sided AKAs (Fig. 3). The results are summarized in Fig. 4. In all cases the AKA was located in the superior aspect of the intervertebral foramen (Fig. 5).

Discussion

To the best of the authors' knowledge, AKA identification and assessment during routine CT examinations has never been evaluated. The Adamkiewicz artery serves as a surgical landmark, but it is also a very important vessel, supplying a large portion of the spinal cord. Precise localization of the AKA is important in the planning of surgical or endovascular treatment. It is necessary to understand the anatomy, physiology and clinical importance of the Adamkiewicz artery, because anatomic iden-

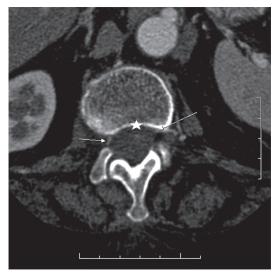


Fig. 6. Contrast-enhanced CT, oblique MIP reconstruction. A rare variant: a bilateral artery of Adamkiewicz at the T9 level in a 46-year-old male patient (white arrows). The ASA is below the white star

tification alone may not always suffice (e.g. in the case of a pathological vessel on the anterior surface of the spinal cord). Firstly, there can be more than one AKA. Koshino et al. found single AKAs in 74% of their patients, while in 26% they saw two or more AKAs; in the patients with two or more AKAs, their origin was unilateral in 57% and bilateral in 43% (Fig. 6).6 Secondly, the Adamkiewicz artery may be anatomically absent, in which case the thoracolumbar spinal cord is supplied with blood by intersegmental collateral arteries. A similar situation can occur when the AKA is functionally absent (e.g. due to atherosclerosis). Thirdly, the great anterior radiculomedullary vein (GARV) is also visible in images; apart from a few details, the GARV is very similar to the AKA. Hyodoh et al. reported that when using MR angiography, the AKA and GARV can appear in the same phase in 46% of cases. Reduced signal intensity in the second phase is characteristic of the AKA, while reduced signal intensity over the 2 dynamic phases is characteristic of the GARV. The GARV has a longer, serpentine intradural trajectory than the AKA; it is located more caudally and has a larger caliber than the AKA. Moreover, the angle between the GARV and the anterior spinal vein (ASV), called a "coat hook" shape, is wider than between the AKA and ASA, which is called a "hairpin turn" connection.^{2,6}

As has also been described in a specimen study, there may be approximately 6–14 anterior medullary arteries that contribute to the anterior spinal artery. In the thoracolumbar region, there is always a dominant great anterior medullary artery called the artery of Adamkiewicz. Thus, in the arterial phase in CT or MR angiography, if there are more enhancing vessels observed originating from an intervertebral foramen between T5 and L2 and continuing toward the ASA, the largest one should be identified as the AKA, and arteries of a smaller diameter should be considered other anterior radiculomedullary arteries.⁷

The ASA varies in size from approximately 0.5 to 0.8 mm in the thoracolumbar region.⁴ Its greatest diameter is at the level of its conjunction with AKA, and usually measures 0.5–0.8 mm, but may be as large as 1.0 mm.⁴ In the thoracolumbar region, the course of the ASA varies from straight (Fig. 5) to somewhat convoluted (Fig. 2).⁵

The imaging method used to detect the AKA should ideally have a high detection rate; be safe to perform and noninvasive; be free of complications during or after the examination; be patient friendly, cheap and widely available; and should allow easy differentiation between the AKA and GARV, providing high spatial and temporal resolution simultaneously.

Computed tomographic angiography (CTA) is the closest to the ideal imaging method, especially nowadays, when multi-detector CT scanners with submillimeter resolution and very high vascular contrast are commonly available. CTA is characterized by high spatial resolution (required for imaging vessels of submillimeter caliber) and high temporal resolution (required for spinal cord vessels with a short transit time from arteries to veins).8 CTA is a very fast, minimally invasive and patient friendly examination. The timing of the contrast administration is essential, since the examination may be diagnostically useless if the contrast is distributed too early or too late in the scanning time. There are many factors which can improve the sensitivity and specificity of CTA in detecting the AKA (e.g. tube voltage, scanning time, contrast dose and flow rate, SNR etc.). According to Takase et al. "To obtain sufficient arterial opacification, rapid injection (4-4.5 mL/s) and a relatively high dose of contrast material (130-150 mL) are necessary to visualize the AKA using CTA"9; in the present study the injection rate was 3.5 mL/s. However, during the examination the patient is exposed to ionizing radiation (although the dose is lower than in digital subtraction angiography), and there is a risk of iodine contrast allergy, contrast-induced nephropathy or other side effects. Thoracoabdominal CTA is associated with a relatively high effective radiation dose of approximately 10 mSv (compared to 14-20 mSv in the present study).2 Boll et al. reported that using a brain reconstruction system can minimize beam hardening artefacts from high-density osseous structures and obscuration of sharp delineation of vasculature. 10 In contrast, in the present study a standard examination protocol was used without using any additional software. 10 Yoshioka et al. used their CTA automatic triggering system for a delayed scan of a 10 mm region of interest (ROI) located in the descending aorta at the level of T7. In their study, aortic density was measured 3 times per s, and when the value reached a point of 130 HU, a helical CT began automatic scanning.¹¹ Boll et al. used a similar system called automatic bolus tracking, with the peak of enhancement at 150 HU, after which scanning was automatically initiated. When performing an examination that aims to detect the AKA - a vessel characterized by a variable and

wide range of origin – it is very important to set a wide range for the scanned area. Enlargement of the cranio-caudal scanning direction takes a few s in CTA, which is superior to magnetic resonance angiography (MRA), in which it takes a few min or longer.⁸ An advantage of both CTA and MRA is that they can be performed by technicians, while digital subtraction angiography (DSA) requires an experienced specialist and is much more difficult and expensive.

Gadolinium-enhanced MRA is characterized by a high AKA detection rate (higher than CTA), though it is more difficult to clearly define the level of the AKA because of low temporal resolution in the sagittal plane, especially in patients with bone pathologies (e.g. scoliosis, osteophytes, narrowing of the intervertebral foramen due to spondylosis). In MRA it is impossible to confirm the continuity of the AKA by generating curved planar reconstruction (CPR) images, due to poor spatial resolution. Moreover, because of a more limited field of view (FOV), segmental collaterals cannot be imaged.⁶ Hyodoh et al. reported an 84% detection rate of the AKA with multi-phase dynamic MRA, but only 48% in single-phase MR angiography, despite the use of a double dose of contrast material to obtain sufficient arterial opacification.¹² Nijenhuis et al. also reported a very high AKA detection rate using two-phase dynamic MRA. 13,14 To improve contrast material distribution, Bley et al. used nitroglycerine for vasospasm prophylaxis in patients undergoing MRA.¹⁵

Selective spinal digital subtraction angiography (SS-DSA) is not a recommended method for detecting the AKA in thoracoabdominal aortic aneurysm (TAAA) patients, because it may cause severe complications, including paraplegia or paraparesis. Maneuvering the catheter through the atherosclerotic aorta and hooking the tip of the catheter into the segmental arteries may induce emboli and subsequent occlusion by disrupting atherosclerotic plagues. Furthermore, injection of a contrast agent into the segmental artery and maneuvering the catheter in this artery can lead to vasospasm and temporary occlusion of the segmental arteries.2 Kieffer et al. reported an 86% AKA detection rate in a study involving 487 SS-DSA procedures, but critical complications occurred in 6 patients (1.2%), including paraplegia, renal failure and stroke; while 2 patients (0.4%) died as a direct result of SS-DSA.¹⁶ The advantage of this method is the possibility to plan endovascular treatment precisely. However, the patient is exposed to high levels of ionizing radiation compared to CTA; furthermore, the examination is time-consuming and requires an experienced specialist. Besides, the contrast material can induce renal failure in patients with a low glomular filtration rate (GFR) more frequently than in a standard CT examination.¹⁴

The newest imaging application for detecting the AKA is intra-arterial CTA (IACTA), developed by Uotani et al. and Furukawa et al. Its advantages are a high detection rate and no complications during or after the examina-

Table 2. Detection rate and left-sided lateralization of the AKA reported in other studies

Author [ref.]	Method	Detection (%)	Right (%)	Left (%)	Range
Furukawa et al.15	IACTA	100	44	56	T5-L4
Boll et al. ⁷	CTA	100	37	63	T8-L2
Charles et al.4	SS-DSA	96	22	78	T8-L2
Alleyne et al.18	CA	90	22	78	T9-L2
Takase et al. ⁶	CTA	90	29	71	T7-L2
Bley et al. ¹²	MRA	88	35	65	T6-L1
Koshino et al. ³	CA	88	28	72	T5-L2
Kieffer et al. ¹³	SS-DSA	86	13	87	T7-L3
Hyodoh et al. ⁹	MRA	82/67	22	78	T7-T12
Yoshioka et al. ²	MRA CTA	67 80	19	81	T7–T12
Nijenhuis et al. ¹⁹	MRA CTA	97 77/31	36	64	T8-L1
Kudo et al. ²⁰	CTA	68	31	69	T10-L2
Melissano et al. ²¹	CTA	67	27	73	T7-L3
Uotani et al. ¹⁴	IACTA IVCTA	94 60	28	72	T7-L2
Williams et al. ²²	SS-DSA	55	15	85	T7-L2
The present study	CT	22	15	85	T5-L2

CA - cadaver anatomy; CTA - computed tomographic angiography; IACTA - intra-arterial computed tomographic angiography; IVCTA - intra-arterial computed tomography; IVCTA - intra-arterial compu

tion. As Uotani et al. noted, IACTA is undoubtedly more invasive than classic intravenous CTA (IVCTA), "but it is nevertheless safer and less time-consuming than selective spinal angiography." ¹⁴ The disadvantage of this method is that it requires DSA for catheter placement (at the proximal portion of the descending aorta) before the examination, which is associated with the same risk as during standard DSA. ^{17,18}

In summary, there are several useful methods to localize the AKA. Although contrast-enhanced MRA or IACTA are considered more effective in detecting this artery, the authors consider CTA the first-line examination to be performed for detection of the AKA. According to the literature, AKA detection rates range from 60–100% for CTA, 67–88% for MRA, 55–96% for DSA and 94–100% for IACTA, as shown in Table 2.

The consecutive routine MDCT examinations analyzed in the present study research were not carried out for the purpose of detecting the AKA, so the contrast dose and injection time (which was constant in the material analyzed: 30 s after injection) may have been insufficient. This was probably the reason that the AKA detection rate using multi-detector CT was only about 22%, which was lower than in other authors' studies (Table 2). To obtain sufficient arterial opacification, rapid injection (4.0–4.5 m/s) with bolus tracking in the aorta and a relatively high dose of contrast material (130–180 mL) are considered necessary to visualize the AKA using CTA, especially in oncological patients with poor veins. 9 Accord-

ing to Nakayama et al., the optimal protocol entails a delay of 18 s after triggering and an iodine dose of 720 mg I/kg body weight. ¹⁹ In the present study it was approximately 530 mg I/kg.

The AKA is a small-diameter vessel surrounded by bony structures and even small artifacts can distort CT images. According to a study of Murthy et al. analyzing 112 angiographs, AKAs were located in the upper half of the foramen in 97% of the cases, and in the upper third in 88%; 9% were located in the middle third; and 2% were located in the lower third. The AKA was never seen in the inferior 1/5 of the foramen. In the present study, the AKA was located in the upper half of the foramen in all cases (Fig. 5). This upper localization of the AKA, close to bone structures (the inferior margin of the superior pedicle), can cause difficulties in imaging of the continuity of the AKA in the foramen (Fig. 3).20 Boll et al. reported that using a brain reconstruction system can minimize beam hardening artifacts from high-density osseous structures and obscuration of sharp delineation of vasculature, while in our study standard protocol and reconstructions were used. 10

The tube voltage of the CT scanner is very important, because lower voltages lead to stronger attenuation by intravascular contrast material compared to higher voltages. In the present study the tube voltage was 120 kV and the detection rate was about 22%, while Nijenhuis et al. reported a 77% detection rate using 80 kV and only 31% using 120 kV (which is much closer to the results of the present study). 13

Nishida et al. demonstrated that model-based iterative reconstruction (MBIR) improves visualization of the Adamkiewicz artery on MDCT compared to adaptive statistical iterative reconstruction (ASIR) and filtered back projection (FBP).²¹ In the present study only a FBP reconstruction algorithm was used.

Detection of the AKA is also determined directly by criteria used for its identification. Hyodoh et al. reported a detection rate of 82% for AKA visualization by the "hairpin turn" connection, while for arterial continuity from the aorta to the ASA it was 67%.¹²

The present authors were not able to assess other conditions of the examined patients (e.g. scoliosis, low cardiac output or atherosclerosis) due to the fact that it was a retrospective study, and no verification with DSA was performed. Because the mean age of the patients in the consecutive MDCT series analyzed in this study was 62 years, many of the patients are likely to have had atherosclerosis, which may have made detection of the AKA very difficult.

Conclusions

The results of the study confirm that the AKA has leftsided lateralization and is most frequently localized between T9 and T12, which is consistent with the initial findings of Adamkiewicz and results reported in the literature (Table 2). The AKA usually originates at a level between T8 and L2. Nevertheless, the origin of AKA was very variable and ranged from T5 in one person to L2 in another patient. Imaging of the AKA is possible as a part of routine CT examinations, but with a significantly lower incidence than in dedicated protocols. For better visualization of the AKA, iterative reconstruction should be used and an arterial phase of CT always has to be started individually (automatic bolus tracking) and the flow rate of contrast administration should not be below 4.5 mL/s. The total amount of contrast should be greater than in a routine CT, and the scanning range should cover at least the area from T5 to L3 level.

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