Influential Factors on the Evaluation of Adamkiewicz Artery Using a 320-Detector Row Computed Tomography Device

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Background: Understanding the difference of Adamkiewicz artery (AKA) presentation in healthy and diseased subjects, and the influence of atherosclerotic factors prevalent in aortic disease patients, are important for aortic disease therapeutic planning. This study used a 320-detector row computed tomography (CT) device to examine the impact of clinical aspects of AKA identification in individuals with and without aortic disease.
Methods: Angio-CTs obtained from 115 patients were assessed and the individuals grouped according to the presence or absence of aortic disease. Datasets were analyzed using OsiriX software, and AKA was identified by three-dimensional multiplanar reconstruction.
Results: The group without aortic disease (Group A) comprised 32 (52.5%) men and 29 women, with a mean age of 53.7 ± 16.8 years. The group with aortic disease (Group B) comprised 31 (57.4%) men and 23 women, with a mean age of 64.8 ± 11.6 years. AKA was identified in 49 (80.3%) participants of Group A and 23 (42.6%) individuals of Group B ($P \leq 0.0001$). In 53 cases (73.6%), AKA originated on the left side. AKA was mainly detected on the left side (73.6%), at the level of T10 to T12 (70%). Tobacco smokers, former smokers, and hypertensive patients had increased odds of having undetected AKA.
Conclusions: Using the method described and a state of the art 320-detector row CT device, AKA was detected more frequently among individuals without aortic disease. Thus, aortic disease and atherosclerotic risk factors hindered AKA detection.

INTRODUCTION

An accurate understanding of spinal cord vascularization is important for therapeutic planning in patients with aortic diseases. However, the vessel pattern is complex and difficult to investigate due to the small caliber of the arteries, the intricate three-dimensional (3D) network that they form, and their wide anatomical variability.[1,2] A previous report[3] raised questions concerning clinical outcomes and preoperative Adamkiewicz artery (AKA) location and patency.

Understanding regarding the differences in AKA presentation in healthy and diseased subjects and

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the influence of common atherosclerotic factors prevalent in aortic disease patients is important to expand the current knowledge about AKA. However, with the exception of a few studies,[4–7] the angio-CT (computed tomography) characteristics of AKA have not been widely investigated in individuals without aortic disease. Indeed, it is possible that preoperative AKA detection could be affected by the same disease it is required for.

The aim of this study is to establish the frequency, characteristics, and the factors that affect AKA detection using a state of the art 320-detector row CT device, in individuals with and without aortic disease. We used the data obtained to determine AKA laterality and the vertebral level of origin.

MATERIALS AND METHODS

Case Series

Volunteers with and without aortic disease were recruited among patients who underwent angio-CT from October 2011 to July 2012 in the Hospital das Clinicas of Faculdade de Medicina of Universidade de São Paulo (HC-FMUSP), Brazil. The examinations were required following clinical suspicion of coronary artery disease, trauma, liver or pancreas disease, and aortic disease.

Inclusion criteria were aortic angio-CT performed with the Aquilion One (Toshiba™ Medical Systems, Otawara, Japan) device, independent of the original indication by their physicians. Exclusion criteria were previous surgery of the descending aorta, individuals with diseases liable to affect the results due to the presence of collateral circulation (Takayasu's arteritis, coarctation of the aorta), with paraplegia or tetraplegia, known allergy to the radiological contrast medium, aortic intramural hematoma, penetrating ulcer of the aorta, and flawed aorta opacification due to technical reasons. Individuals participating in other studies following protocols that could interfere with this study were also excluded. Of the 128 angio-CT examinations performed, 115 were considered eligible (Fig. 1). This study complied with the Declaration of Helsinki and was approved by the research ethics committee of HC-FMUSP. All patients signed an Institutional Review Board-approved informed consent form.

Study Design

A cross-sectional observational analysis of routine angio-CT examinations of outpatients, with or without aortic disease, was performed using the open-source software OsiriX® (Pixmeo, Geneva, Switzerland).[3,8] The presence/location of AKA and the presence/absence of aortic disease, thrombi, and aortic dissection were assessed by a single experienced examiner in 2 different moments[3,9] and validated by a second using the best quality images obtained for each of the study's participants. The second assessment was blinded to the presence of AKA, as the examiner did not focus on the spinal cord space. Both examiners were blinded to the original reason for requesting the examinations.

Participants were categorized according to the following parameters: gender, age, ethnicity, weight, height, and body mass index (BMI). Clinical information such as hypertension, diabetes mellitus, dyslipidemia, tobacco smoking, and metabolic syndrome was collected during clinical interview and review of the laboratory examination results, just after the angio-CT.

Hypertension was defined as the use of antihypertensive drugs and systolic pressure over 140 mm Hg or diastolic pressure over 90 mm Hg. Diabetes mellitus was defined by the use of antidiabetic medication or by 2 laboratorial glycemia measurements above 126 mg/dL. Tobacco smoking was defined as smoking one or more cigarettes in the last 30 days; former smokers were those whose last cigarette was smoked more than 30 days before the examination. Dyslipidemia was defined by the use of antilipidemic agents or by increased low-density lipoprotein cholesterol ($\geq$160 mg/dL), triglycerides ($\geq$150 mg/dL), or decreased high-density lipoprotein cholesterol ($<$40 mg/dL in men and $<$50 mg/dL in women). Metabolic syndrome was diagnosed by the co-occurrence of 3 of the 5 of the following medical conditions: abdominal (central) obesity, high blood pressure, high fasting plasma glucose rates, high serum triglycerides, and low high-density lipoprotein cholesterol levels.[10]

Allocation of the participants to the study groups was performed only after the presence or absence of aortic disease was established, and was not based on the original indication of angio-CT.

Imaging Methods

Angio-CT followed a pre-established protocol. All examinations used the same 320-detector row device, equipped with software for ultra-helical scan mode. The arterial-phase, contrast-enhanced protocol involved an intravenous injection of 90–100 mL of nonionic tri-iodinated contrast medium over 30 sec at a velocity of 4–5 mL/sec using a pump; the trigger threshold level was set at 150 HU to achieve greater contrast concentration in the descending aorta.

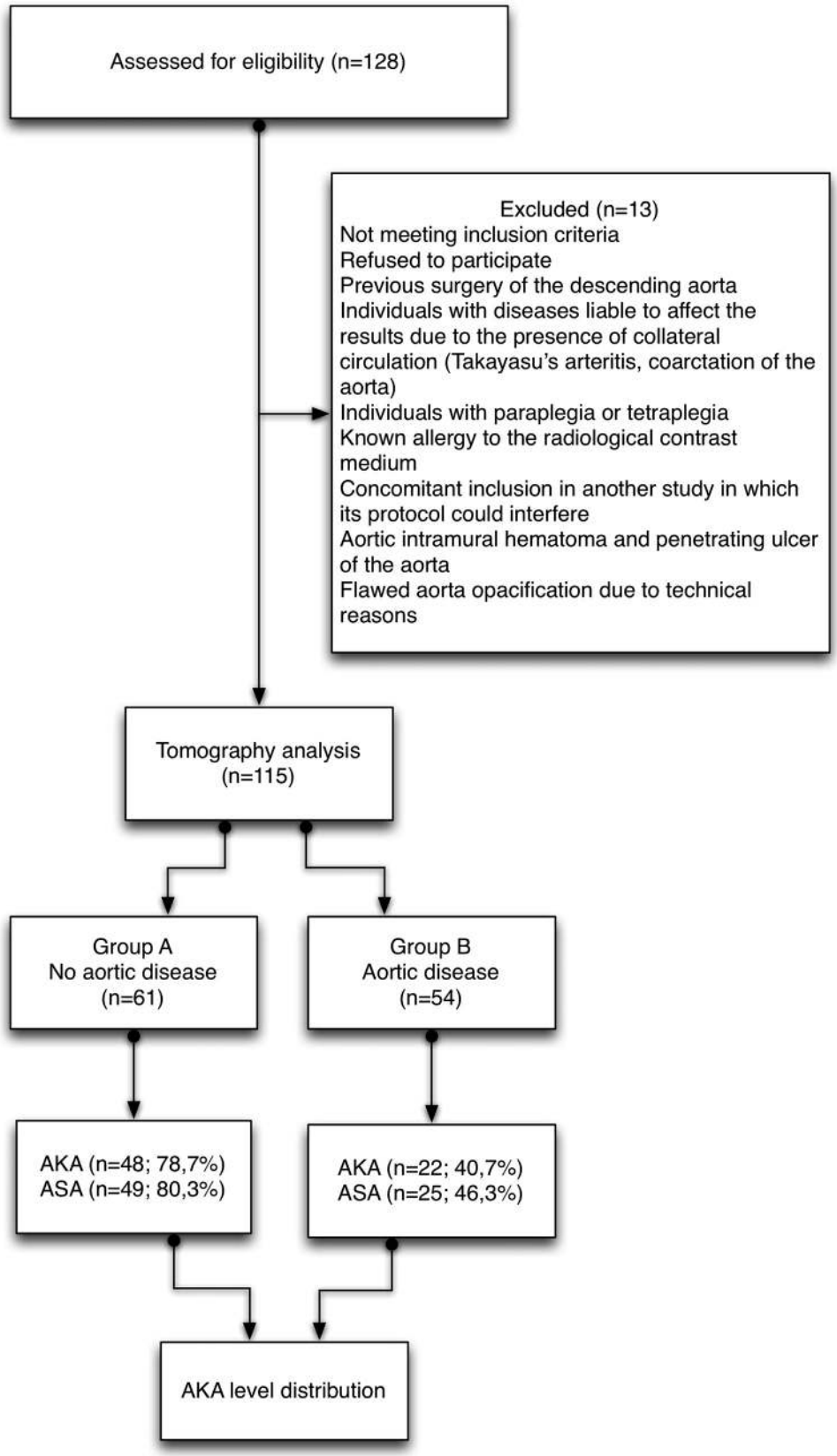

Fig. 1. Flow chart of patient selection and group assignment.

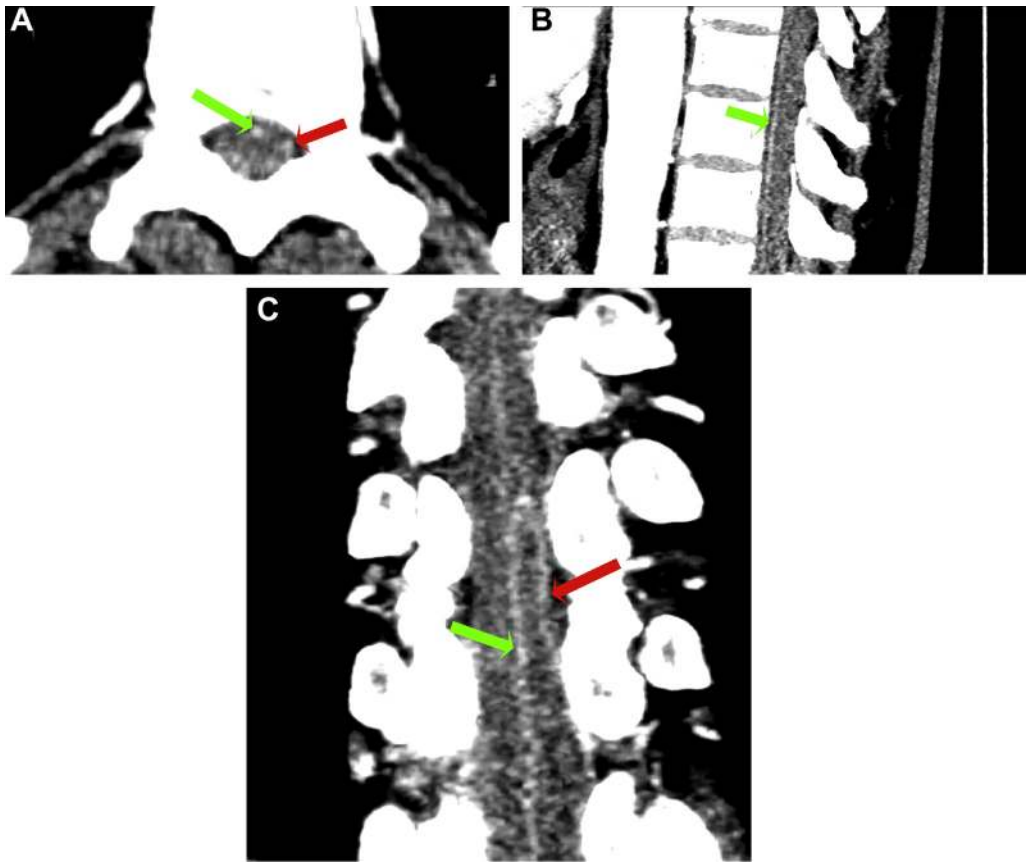

Fig. 2. (A) Sagittal view, **(B)** axial view, and **(C)** oblique/coronal view. *Green arrow*: ASA; *red arrow*: AKA.

Image postprocessing was performed using OsiriX software, as previously described.[3] First, axial images were scrolled at a large magnification and examined for the presence of 2 dense points in the spinal cord, corresponding to the anterior spinal artery (ASA) and to the AKA (Fig. 2A), which allowed for the cranial–caudal trajectory to be traced. Then, the 3D multiplanar reconstruction mode was used enabling the simultaneous visualization of 3 oblique planes mutually convergent at 90° on 3 windows (the lower left window initially presents axial images). Finally, the manual shift of the crosshair permitted assessment of the full spinal cord (Fig. 2). A video illustrating this technique is available at http://vascular.pro/aka.html.

The point where the axes cross was placed on the spinal cord, at the level of the last thoracic vertebra, and a sagittal image was created in the upper left window (Fig. 2B). Adjusting the axis position, angling on the longitudinal direction to encompass most of the spinal cord in the upper left window, and changing the section thickness using a maximum intensity projection algorithm and ''windowing'' allowed for an almost coronal or paracoronal oblique view in the largest window (Fig. 2C). In addition, tilting the axes angle and scrolling the images along the anterior–posterior direction enabled rapid scanning of the full spinal cord.[3]

Visualized with the help of the 3D multiplanar reconstruction, AKA was identified as the vessel ascending in the direction of the anterior mid-sagittal surface of the spinal cord from the intervertebral space and joined the ASA via a characteristic hairpin (Fig. 2C). The following criteria were applied to identify the ASA, the AKA, and the connecting segmental artery (Fig. 3): continuity of the vessel with the intercostal artery or the aorta[11–14]; the simultaneous identification of AKA and ASA as 2 dense points in the anterior region of the spinal cord on consecutive axial images[12,14,15] (Fig. 2A); the presence of the characteristic hairpin configuration of AKA joining the ASA[14]; and the association between flaws in opacification of the posterior spinal vein and other veins around the spinal cord

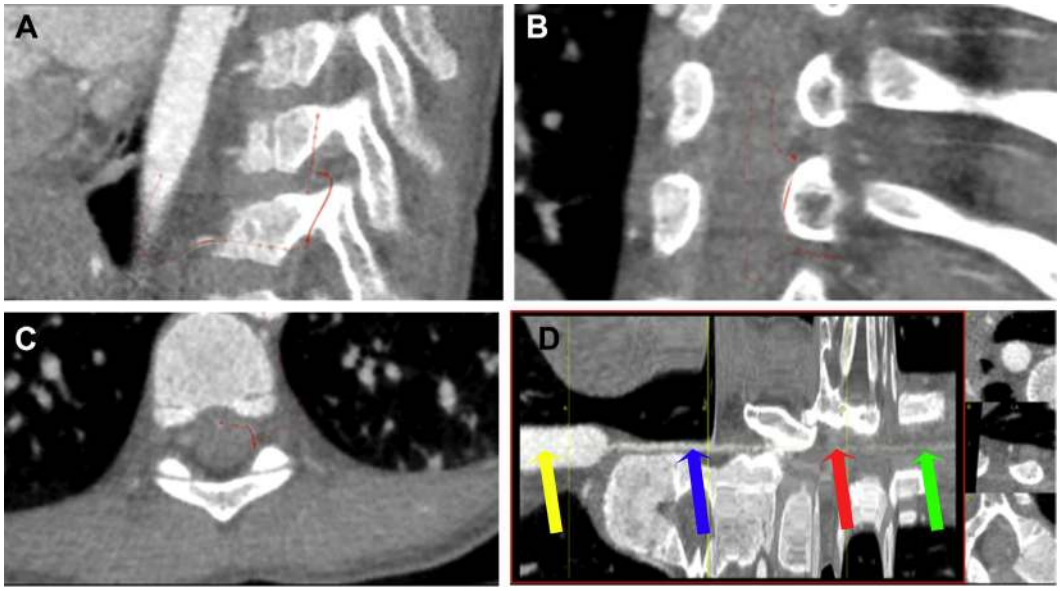

Fig. 3. (A–C) Oblique cut showing vessel tri-dimensional path. **(D)** Tri-dimensional curved reconstruction of AKA continuity from aorta to the ASA. *Yellow arrow*: aorta; *blue arrow*: intercostal artery; *red arrow*: AKA; *green arrow*: ASA.

(intercostal, lumbar, and azygos veins),[15] allied with the previous criteria.

The full set of AKA, identified as described above, was assessed by blinded evaluators to confirm or not the presence of thoracic aortic disease, as described below. AKA was also analyzed according to its vertebral level of origin (T7–L3) and to its laterality (right or left). AKA level corresponded to the point of spinal canal entry, rather than the level of its continuation into the ASA.

Following the assessment of AKA, the presence of aortic disease was evaluated with tomography, in a blinded manner, as described below.

Criteria for absence of aortic disease. Individuals without descending aortic disease detectable by CT and individuals with mild atherosclerosis and Montgomery Class I (no intimal thickness), II (intimal thickness 1–3.9 mm), or III (atheroma <4 mm),[16] without hemodynamic repercussion in the spinal cord circulation, were allocated to group A (without aortic disease).

Criteria for presence of aortic disease. Individuals with severe atherosclerosis and Montgomery Class IV (atheroma or intimal thickness > 4 mm)[16,17] and those with atheromatous plaques on the posterior aortic wall were allocated to Group B (with aortic disease). Type B aortic dissection was defined as the presence of delamination, with an intimal ''flap'' image inside the arterial lumen. Mural thrombus was defined as a low-density internally irregular filling defect adhered to the arterial wall, and aneurysm was defined as a 50% dilatation of the normal aorta.[18]

Statistical Analyses

A sample size of 37 for each group was calculated to show 30% of proportion difference considering bilateral hypothesis, 5% significance, and 90% statistical power. Data were entered in a safe online database. After verifying data consistency, a descriptive analysis of the characteristics of the participants in each group was performed. Categorical data were analyzed as absolute frequencies and proportions. For quantitative data, mean, standard deviation, maximum, and minimum values were described. Asymmetric and normal continuous variables were described as medians and means. The normality of the data was assessed by visual histogram inspection and the D'Agostino-Pearson test. Fisher's exact test was used for intergroup comparison, means were compared using the unpaired Student's *t*-test, and medians were analyzed with the Mann–Whitney test. Univariate and multiple logistic regression analyses based on the maximum likelihood method were used to investigate the association of cardiovascular risk factors with the AKA identification. Odds ratios (95% confidence intervals) were calculated by logistic regression analysis. Values lower than 0.05 were considered statistically significant. Statistical analysis was performed using SAS 9.2 (Statistical Analysis System, Cary, NC).

Table I. Comparison of the sociodemographic data for the 2 groups of participants

Characteristic	Group A (without aortic disease) $n = 61$ (53%)	Group B (aortic disease) $n = 54$ (47%)	Total $n = 115$	P value
Gender				
Male	32 (52.5%)	31 (57.4%)	63 (54.8%)	0.5946
Female	29 (47.5%)	23 (42.6%)	52 (45.4%)	
Age (years)				
Mean ± SD	53.7 ± 16.8	64.8 ± 11.6		< 0.0001[a]
BMI				
Mean ± SD	27.4 ± 5.9	26.6 ± 4.8		0.3041
Contrast (mL)				
Mean ± SD	93.6 ± 23.8	92.9 ± 16.9		0.7210
Ethnicity				0.4351
Asian	2 (4.1%)	4 (9.1%)	6 (6.5%)	
White	30 (61.2%)	27 (61.4%)	57 (61.3%)	
Brown skin	15 (30.6%)	9 (20.5%)	24 (25.8%)	
Black	2 (4.1%)	4 (9.1%)	6 (6.5%)	
AKA				
Left side	37 (75.5%)	16 (69.5%)	53 (73.6%)	
Right side	12 (24.5%)	7 (30.5%)	19 (26.4%)	
Total	49 (80.3%)	23 (42.6%)	72 (62.6%)	< 0.0001

The data corresponding to categorical variables are expressed as simple frequencies (percentages).
[a]Statistically significant in the chi-squared test.

RESULTS

This study included 115 individuals assigned into 2 groups: Group A comprised 61 individuals without aortic disease and Group B comprised 54 participants with aortic disease.

Both groups were sociodemographically similar, except for the age item (Table I). A similar amount of contrast medium was used in both groups. AKA was significantly more identified in Group A (80.3%) than in Group B (42.6%). It was also more frequently located at the left side (73.6%) in both groups ($P < 0.0001$).

Figure 4 shows the results of univariate logistic regression. Figure 5 shows the multivariate logistic regression analysis for all study subjects. Atherosclerotic risk factors such as being a smoker, a former smoker, and having hypertension were significantly associated with nondetection of AKA. All the other risk factors evaluated were associated with low rates of AKA detection.

The analysis of aortic disease distribution among the individuals assigned to Group B revealed that 14 (25.9%) exhibited dissection, 27 (50%) had mural thrombi, and 42 (77.8%) had aneurysms (Table II). Aneurysm was the most frequent aortic disease in Group B.

Figure 6 depicts the distribution of the vertebral levels of origin of AKA. Visual inspection suggests a Gaussian distribution.

DISCUSSION

In this study, AKA was detected in 80.3% of the participants without aortic disease and in 42.6% with aortic disease (average of 62.6% of all participants). According to previous studies, AKA is detected in approximately 70% of cases,[3,13,19,20] a rate similar to the revealed herein. Non-aortopathic studies have a higher rate of AKA detection (94.22%) than the one found in this study,[4–7] but none of them evaluated the influence of atherosclerotic variables in AKA detection. Group selection and the different populations studied could underlie these discrepancies.

Initially, advances in tomography technology and the number of detectors led to improvements in AKA detection, from 60% with 4–16 detectors[6,7,13,14,21–25] to 75% with 40–64 detectors.[1,4,5,20,26] Currently, there are no reports using more than 64 detectors; our study used a state of the art 320-row CT scan, and still did not improve the detection rate, suggesting that the CT scan technology reached the best image it can provide for AKA detection.

Previous studies that focused on the detection of AKA of individuals with[3,12,14,20–26] or without[4–7] aortic disease showed variable rates of detection. Our study is the first to use the same device and method to analyze these 2 groups of individuals to investigate whether the healthy or diseased

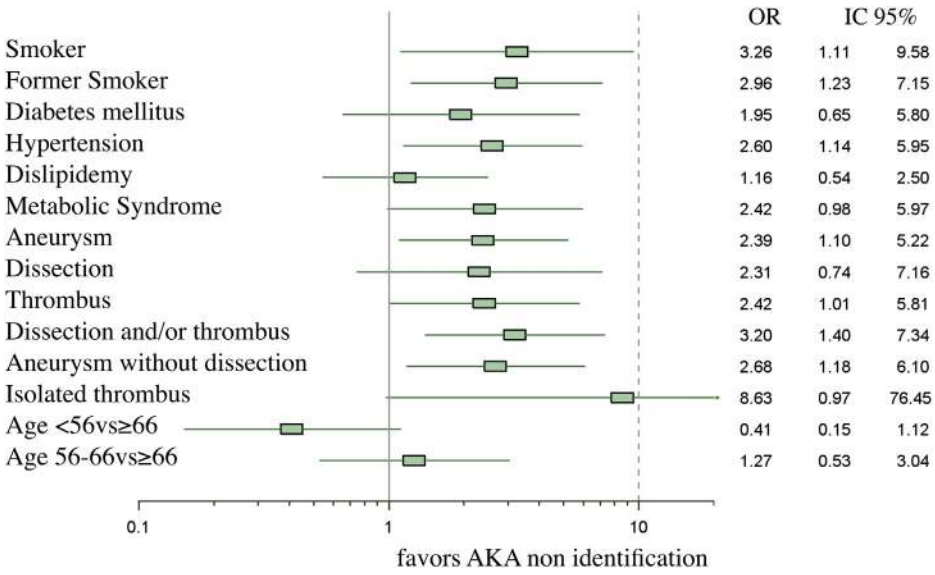

Fig. 4. Odds ratio plot of univariate logistic regression analysis of variables for lack of AKA detection.

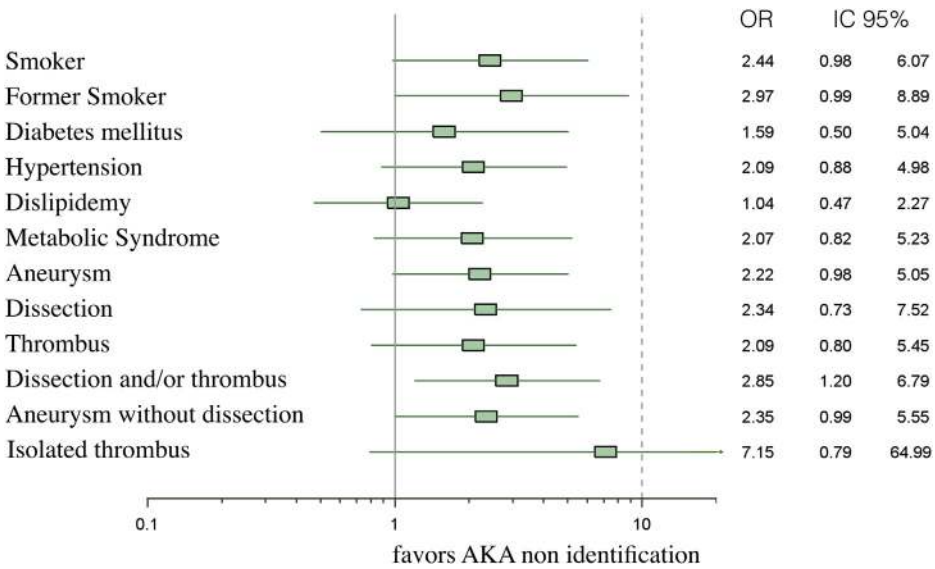

Fig. 5. Odds ratio plot of multiple logistic regression analysis for lack of AKA detection adjusted by tertiles of age (first tertile <56, second tertile 56–66, third tertile ≥ 66) obtained from 11 models of multiple logistic regression.

condition affects the rate of AKA detection by CT scan technology. The data revealed that diseased aortas correlate with a lower rate of AKA detection.

Angio-CT was chosen as the imaging method because it currently represents the gold standard for preoperative assessment of individuals with arterial diseases due to its speed, reproducibility, sensitivity, and specificity for the detection of atherosclerosis and other aortic diseases.[17] Moreover, angio-CT is available in most of the major health clinics, being mandatory in the endovascular planning of aorta surgeries. The approach can detect the main artery that supplies blood to the spinal cord without having to change the technique significantly.

In this study, we sought to minimize the radiation to reduce its associated risks by using a dose considered to be safe and reproducible; however, the strategy limited the quality of the images acquired. Thin arteries, such as those that constitute the spinal cord

Table II. Redistribution of participants with aortic diseases according to the presence or absence of AKA

Comorbidities Group B	Without AKA $n = 32$	With AKA $n = 22$	Total $n = 54$	P value
Dissection	8 (57.1%)	6 (42.9%)	14 (25.9%)	0.8515
Mural thrombus	15 (55.5%)	12 (45.5%)	27 (50%)	0.5796
Aortic aneurysm	22 (52.4%)	20 (47.6%)	42 (77.8%)	0.0543
Dissection or mural thrombus	20 (58.8%)	14 (41.2%)	34 (63%)	0.9323[a]

The data are expressed as simple frequencies (percentages).
[a]Statistically significant in the chi-square test.

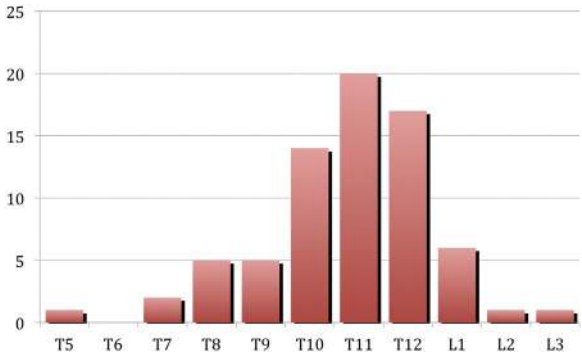

Fig. 6. Distribution of AKA vertebral level of origin, independent of laterality.

vascularization, are within angio-CT's detection range.[4] This fact notwithstanding, few studies have been able to identify AKA in 100% of the patients, partly due to technical reasons and because most studies were conducted only in individuals with aortic disease. In contrast, detection rates reported for individuals with healthy aortas were higher.[4–7] It is known that intra-arterial injection of contrast medium yields impressive images, with rates of AKA detection ranging from 94.1% to 100%. However, this method is highly invasive and is not part of the preoperative routine in most centres.[21]

Computed tomography is based on the emission of X-rays, which are preferentially absorbed by bone tissue. As the arteries investigated are located within a high-density bone structure, artifacts may occur during image acquisition, although modern equipment minimizes this problem. Nevertheless, it remains difficult to distinguish AKA from the vessel network using angio-CT, mainly because the anterior median spinal vein drains into a radicular vein with a shape similar to AKA at precisely the anterior region where the vein caliber is greater and thus most easily visualized.[2,15] For these reasons, Backes and Nijenhuis[27] criticized the exclusive use of anatomical criteria to evaluate spinal cord vascularization with angio-CT.

Obesity can interfere with the results of angio-CT, because X-rays are absorbed by the adipose tissue, increasing noise and reducing the signal/noise and contrast/noise ratios, thereby making image analysis more difficult. The occurrence of this interference may explain why a study conducted with Japanese individuals, who are usually leaner than European and American patients, yielded better AKA detection rates.[20,23] Similarly, studies involving cancer patients[4,7] and children[5] demonstrated excellent results. In this study, the average BMI was 26.9 kg/m^2 in the group without aortic disease and 26 kg/m^2 in the group with aortic disease. The BMI recorded for both study groups was higher than the average BMI reported for the Japanese individuals (21.9 kg/m^2) and lower than the average American BMI (28.3 kg/m^2).[28]

The average age was lower in patients in Group A (53.7 years) than in Group B (64.8 years, $P < 0.0001$), most probably because age is a risk factor for atherosclerosis and aortic disease.[29] In both study groups, the predominant location of AKA was on the left side. We also found that AKA was more frequently located between T10 and T12 (70%), whereas previous reports have documented the artery's location level between T9 and T11 (63%).[3] This discrepancy probably reflects the fact that these authors analyzed the spinal artery continuation of AKA, and not the feeder portion. The frequent location of AKA on the left side may have been due to the smaller distance and sinuousness between the aorta and ASA, as well as to the reduced tortuosity, on that side.[30]

Atherosclerotic risk factors and the presence of aortic aneurysm, dissection, mural thrombus, and association of mural thrombus or dissection decreased the identification of AKA (Figs. 4 and 5). Aneurysm was the factor that best associated with low AKA identification. Thus, aneurysm is both the reason underlying the need for AKA location in preoperative therapeutic planning and the factor leading to a failure in AKA detection in many individuals.

Plausible explanations as to why AKA detection was not possible in some patients include the following: AKA may have suffered thrombosis, is nonexistent or kinked by anatomic distortion, has a slow flow or a dissection flap occlusion, or is just too small to be visualized with the current method. In the latter case, spinal cord vascularization would have to rely mostly on collaterals. The result could be that surgical occlusion of other entry points, in patients with undetected AKA, would increase the risk of spinal cord ischemia,[31] whereas surgical blocking of the risk zone (T10 to T12) would not have increased the risk of paraplegia (Fig. 6). A slower blood flow may require a later CT phase scan to improve AKA detection, but further studies are needed to test this hypothesis.

Avoiding AKA occlusion during aortic surgery may help to prevent paraplegia[9] and therefore determining AKA detection is an important preoperative therapeutic planning step for aortic disease patients. Factors that influence AKA detection could modify the current standards employed to prevent spinal cord irrigation during open or endovascular procedures. However, the relevance of AKA preservation to reduce the risk of spinal cord ischemia in aortic and neurologic surgical procedures is yet to be established.[32] Our data also reveal that increasing CT row detectors and lowering radiation did not improve image quality and AKA detection. Nevertheless, the clinical importance of AKA for aortic diseases remains elusive and studies to this effect are warranted. Usage of the widely available 64-row CT scan and accessible software[3] should enable researchers to search answers regarding this important question.

Although it is difficult to blind the examiner for an aorta view before AKA detection, this limitation was minimized by starting the analysis with a full zoom of the spinal cord space. Another limitation of this study is the lack of results using a low-risk gold standard to compare with results described herein.

In conclusion, our findings reveal that the rate of AKA detection with angio-CT is different for healthy individuals and diseased aorta patients. Indeed, AKA was more often detected in individuals without aortic disease and atherosclerotic risk factors, and more frequently observed on the left side at the vertebral level T10 to T12. Atherosclerotic risk factors and the presence of an aortic aneurysm, dissection, mural thrombus, and association of mural thrombus or dissection hindered detection of AKA.

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