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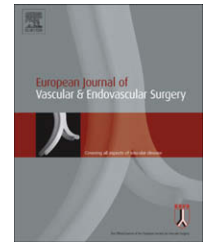

Demonstration of the Adamkiewicz Artery by Multidetector Computed Tomography Angiography Analysed with the Open-Source Software OsiriX

G. Melissano [a,*], L. Bertoglio [a], V. Civelli [b], A.C. Moraes Amato [a], G. Coppi [a], E. Civilini [a], G. Calori [c], F. De Cobelli [b], A. Del Maschio [b], R. Chiesa [a]

[a] *Scientific Institute H. San Raffaele, Chair of Vascular Surgery, Vita Salute San Raffaele University, Milan, Italy*
[b] *Scientific Institute H. San Raffaele, Department of Radiology, Vita Salute San Raffaele University, Milan, Italy*
[c] *Scientific Institute H. San Raffaele, Statistical Unit, Vita Salute San Raffaele University, Milan Italy*

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Abstract *Objective:* To evaluate the feasibility of the Adamkiewicz artery (AKA) detection by multidetector computed tomography (CT) data analysis without the need of a dedicated workstation, using low-cost hardware and the freeware OsiriX.
Methods: CT scans of 67 patients undergoing a thoracic or thoraco-abdominal aortic procedure between April 2006 and August 2008 were evaluated with respect to detection rate and AKA level and side using the OsiriX software version 3.2 on Mac OS X computer and compared to results obtained by standard workstation analysis, in a fully blinded analysis. The results were also compared with data compiled from a review of the English-language literature on this topic.
Results: (1) AKA identification showed a substantial agreement of 85.07% between the methods ($k = 0.636$). (2) The comparison of AKA level showed a substantial agreement (weighted $k = 0.661$), with consensus in 70.14%. (3) From the literature review, we found that recognition of the AKA was achieved in 466 of 555 cases (83.96%). (4) In 384 (83.3%) cases the AKA originated from a left intercostal artery. (5) The proposed method and literature-compiled data showed a similar AKA level distribution.
Conclusions: Noninvasive AKA location with open-source software and low-cost hardware is feasible. The OsiriX software allows to effectively navigate through CT data not only to study the aorta, but also to detect the AKA, as in the case of the standard method and the literature data. Its availability and ease of use may contribute to make identification of the AKA part of the routine evaluation of CT scans in patients with aortic disease, even where dedicated workstations are not available, with potential benefits for planning therapeutic procedures.

* Corresponding author. Dr. Germano Melissano, MD. Via Olgettina 60, Milan 20090, Italy. Tel.: +390226437146; fax: +390226437148.
E-mail address: g.melissano@hsr.it (G. Melissano).

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The importance of a preoperative knowledge of the location of the Adamkiewicz artery (AKA) before thoracic and thoraco-abdominal aortic surgery was demonstrated by Kieffer and co-workers back in the 1980s.[1] The complexity and invasiveness of the method, however, prevented its widespread diffusion.

There is growing evidence that the AKA may, nowadays, be visualised through noninvasive methods, such as magnetic resonance angiography (MRA)[2] or computed tomographic angiography (CTA). These methods, however, often necessitate special sequences, or contrast administration protocols,[3] and rely on some degree of post-processing techniques that require a powerful, but expensive, dedicated workstation and may be quite resource consuming. Thus, in most centres, it is not part of the routine analysis of scans performed for aortic pathology.

Nowadays, a very interesting alternative to dedicated workstations is available: it is a software called OsiriX, developed only a few years ago. This interactive navigation program, designed by Ratib and Rosset from the Department of Medical Imaging and Information Science of the University Hospital of Geneva, Switzerland, allows rendering and analysis of several different advanced medical imaging modalities (i.e., CTA, MRA, etc.).[4] It is distributed free of charge and the source code is available under the GNU General Public License open-source licensing agreement for other institutions to enhance and improve the existing version. It runs on a regular laptop or desktop Mac OS X computer[4–7] and allows accurate rendering and measuring of the aorta and its branches, allowing adequate planning for surgical and endovascular procedures.

This study aims to verify the feasibility of AKA detection on preoperative CT scans of patients, who were admitted at our institution for thoracic or thoraco-abdominal aortic disease, using low-cost hardware and the OsiriX freeware, comparing the results to standard workstation analysis in a double-blinded fashion.

Materials and Methods

Patients

Preoperative CT scans of 67 patients undergoing a thoracic or thoraco-abdominal aortic procedure between April 2006 and August 2008 at our institution were analysed. Diseases included thoracic aneurysm (17 patients, 25.4%), thoraco-abdominal aneurysms (40 patients, 59.7%), dissection (nine patients, 13.4%) and pseudo-aneurysm (one patient, 1.5%). There were 57 (85.1%) males and 10 (14.9%) females. The age range of patients was from 43 to 81 years (median: 65.67).

Imaging protocol

All the CT scans were performed at our institution on a Toshiba Aquilion™ 64-row scanner. Scan parameters were 120 kv, 350 mA, individual detector collimation 64×0.5 mm, 32-mm detector length, gantry rotation time of 0.40 s, slice thickness of 1 mm or less and space between slices of 0.75 mm. Our routine protocol for aortic pathology study was performed, which included an arterial phase contrasted by 100–110 ml of Iomeron® iomeprol (a tri-iodinated, non-ionic contrast agent, in 3.7 mg ml^{-1} concentration), administered intravenously in 30 s.

Image analysis

Analyses with both the standard method (Vitrea® workstation, Vital Images Inc.) and proposed method (OsiriX software version 3.2.1 on a regular Mac OS X computer) were performed by a single, different physician unaware of the results of the other methods. Best CT two-dimensional (2D) multiplanar reconstruction (MPR) image or series of images obtained for each patient using the proposed and standard methods were anonymised and saved as a Digital Imaging and Communications in Medicine (DICOM) image. Another method-blinded, senior specialist double checked all the anonymous DICOM images to certify the detection/absence of AKA.

To demonstrate the AKA, axial images were scrolled, looking for the anterior spinal artery and a probable AKA. The AKA is defined as the most dominant anterior radiculomedullary artery and has a diameter of 0.8–1.3 mm.[8] Typically, using the 2D MPR, the first window shows an axial view of the arterial phase scans (Fig. 1A) – the cross-hair is placed on the spinal cord at the level of the last thoracic vertebrae and a sagittal view of the spinal cord is produced, which is displayed in the second window (Fig. 1B). On adjusting the position and the angulation of the cross-hair in the second window, a coronal or paracoronal view of the spinal cord is produced in the third window (Fig. 1C). Scrolling the cross-hair and tilting the angle of the final window will allow a quick exploration of the whole spinal cord.

The AKA is identified on a morphological basis: the anterior spinal artery is identified quite easily as a thin longitudinal vessel running in the anterior aspect of the spinal cord. When present, the AKA is straightforwardly identified by its characteristic 'hairpin' aspect. Remembering that we are analysing a paracoronal view, the course of the AKA may run through different planes; therefore, we may need to scroll through a few different images, slightly tilt the reformatting plane or use a thicker slab to optimise the visualisation (Video 1)[a]. An improvement of the image may be achieved using maximum intensity projection (MIP) with 2–5 slices. The anatomical level of the intercostal/lumbar artery is defined as the level of the vertebra below which the intercostal/lumbar artery runs. The whole thoraco-lumbar spinal cord was explored even after the AKA was detected in order to avoid missing multiple AKAs. Curved multiplanar reconstruction (2D curved-MPR) can be used to demonstrate a connection from the aorta to the anterior spinal artery by the AKA (Fig. 2), and its continuity; however, it was not part of the analysis for this study.

Literature review

We reviewed the English-language literature published between 2000 and 2008, found by researching the MEDLINE database, related to noninvasive radiological visualisation of the AKA, using the terms 'Adamkiewicz' and

[a] Video 1: Video demonstration of the OsiriX method available at: http://www.vascular.cc/aka.html.

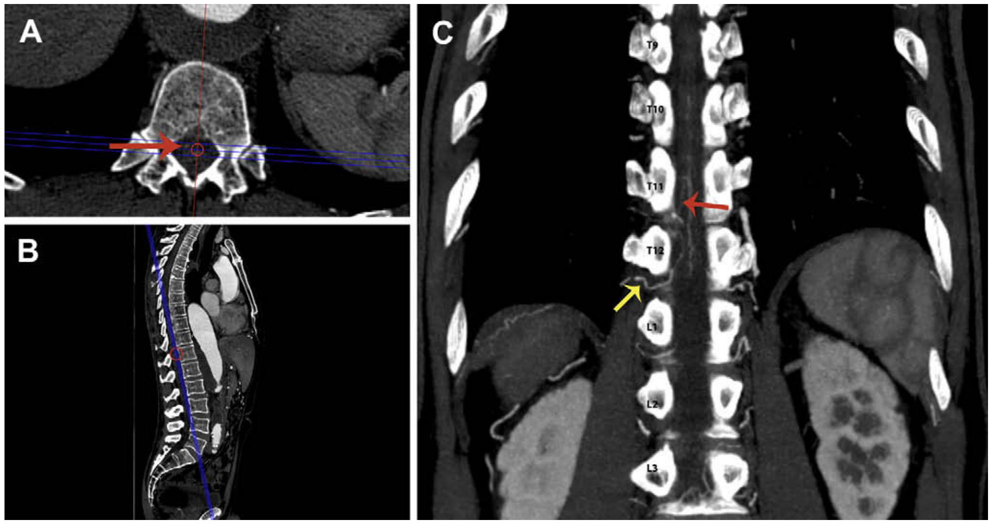

Figure 1 (A) Axial view of the arterial-phase scans, the cross-hair is placed on the spinal cord at the level of the last thoracic vertebral, producing (B) a sagittal view of the spinal cord that is displayed in the second window. (C) A coronal or paracoronal view of the spinal cord is viewed in the third window. Yellow arrows point to intercostal artery and red arrows point to AKA.

('tomography' or 'magnetic resonance'). All the 79 resulting papers and their references were checked concerning the presence of aortic disease, methods of scanning, AKA presence, level and side. Eleven papers that met all these criteria were selected, and the data were compiled.

Statistical analysis

The AKA level was considered consensus when the original level was within one intercostal space above or below. Statistical analyses were performed using the SAS v.8 software (SAS Institute Inc., Cary, NC, USA). Cohen's kappa was used for inter-rater agreement between proposed and standard methods and interpreted as proposed by Landis and Koch (≤ 0 = poor, 0.01—0.2 = slight, 0.21—0.4 = fair, 0.41—60 = moderate, 0.61—0.80 = substantial and 0.81—1 = almost perfect)[9] and the Mann—Whitney test was used for comparing the distribution of our sample results with the literature.

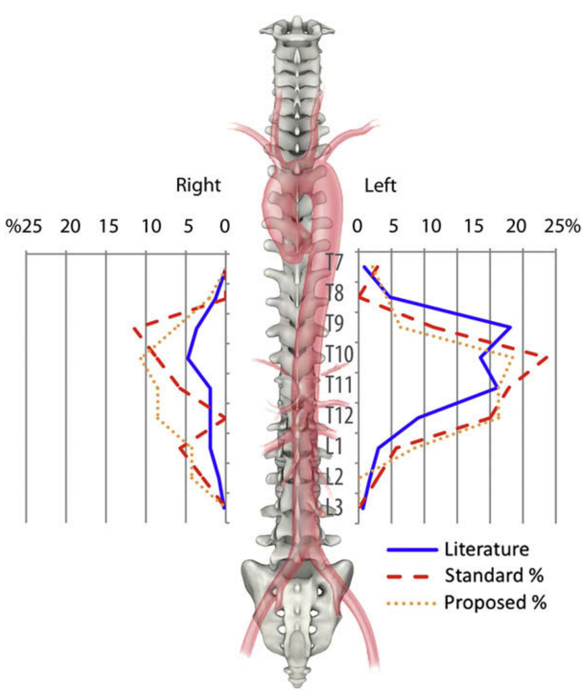

Figure 2 Percentage of AKA origin level in relation to the intercostal artery, its location and method used. Note the higher left T9—T12 prevalence.

Results

We reviewed a total of 11 relevant papers from 2000 to 2008, where the AKA was visualised in patients with vascular diseases through gadolinium-enhanced MRA or CTA; in the second case, contrast was injected through either a peripheral vein (intravenous CTA) or directly into the thoracic aorta by a pigtail catheter (intra-arterial CTA).[8,10—19] Case or anecdotal reports were excluded from the results for this review (Table 1).

These papers studied 495 patients with thoracic and thoraco-abdominal aortic aneurysm (TAAA), thoracic pseudo-aneurysm, penetrating aortic ulcers and thoracic aortic dissection, who underwent a total of 555 examinations aimed at the visualisation of the AKA (some patients underwent both MRI and CT scans in comparative studies). Recognition of the AKA was achieved in 466 out of 555 scans (83.96%, confidence interval (CI) 95%: 0.809—0.87). In particular, the origin of the AKA was deemed recognisable in 417 (80.8%) patients. In 384 (83.3%, 95% CI: 0.799—0.867) cases, the AKA originated from a left intercostal artery and in 77 (16.7, 95% CI: 0.133—0.201) cases, it originated from a right intercostal artery (Fig. 3). Some studies also considered the presence of more than one AKA for each patient. This aspect, however, was studied in 328 cases and a double AKA was found in 54 (16.4%, 95% CI: 0.124—0.204).

In our patients, CT data analysed with the standard method showed the AKA in 45 (67.16%) patients, with a higher left prevalence (73%). The CT data analysed by the proposed method using OsiriX software demonstrated AKA in 51 (76.1%) patients, with a higher left prevalence (66.1%)

Table 1 Summary of the studies' results used in literature review

Author/Year of publication	Method	Total		T7	T8	T9	T10	T11	T12	L1	L2	L3	Total
Uotani et al. 2008[17]	CTA	25	Left	1	1	6	6	1	1	0	2	0	18
(intravenous and intra-arterial)			Right	0	0	2	3	1	1	0	0	0	7
Hyodoh et al. 2007[10]	MRA	158	Left	0	6	48	40	43	14	0	0	0	151
			Right	0	2	3	1	1	0	0	0	0	7
Schurink et al. 2007[15]	MRA	9	Left	0	0	0	2	2	2	0	0	0	6
			Right	0	0	0	1	1	1	0	0	0	3
Nojiri et al. 2007[14]	CTA	35	Left	0	0	5	4	2	3	2	2	3	21
			Right	0	1	3	5	0	0	4	0	1	14
Yoshioka et al. 2006[19]	CTA and MRA	29	Left	0	2	4	7	3	2	3	0	0	21
			Right	0	0	1	2	2	2	1	0	0	8
Nijenhuis et al. 2005[13]	MRA	11	Left	0	0	2	2	2	2	0	0	0	8
			Right	0	0	1	0	0	0	1	1	0	3
Hyodoh et al. 2005[11]	MRA	42	Left	1	3	8	9	17	3	0	0	0	41
			Right	0	0	0	0	1	0	0	0	0	1
Yoshioka et al. 2003[8]	CTA and MRA	17	Left	1	2	8	7	3	1	0	0	0	22
			Right	0	0	2	3	0	0	0	0	0	5
Takase et al. 2002[16]	CTA	78	Left	1	6	14	1	14	9	6	3	0	54
			Right	0	1	5	6	3	4	2	3	0	24
Kawaharada et al. 2002[12]	MRA	29	Left	0	0	5	7	8	5	3	1	0	29
			Right	0	0	0	0	0	0	0	0	0	0
Yamada et al. 2000[18]	MRA	18	Left	0	2	7	1	3	0	0	0	0	13
			Right	0	2	0	1	0	1	1	0	0	5
Total		464		4	28	124	107	107	50	23	12	4	

and without statistically significant difference from the literature ($p = 0.119$, Fisher's exact test). Double AKA was found in seven (10.44%) patients using the proposed method. Disagreement among operators and the senior double-checker was recorded in five cases. Results from the proposed method and compiled data from the literature regarding AKA level have similar distribution, without a statistically significant difference ($p = 0.5376$, Mann–Whitney test).

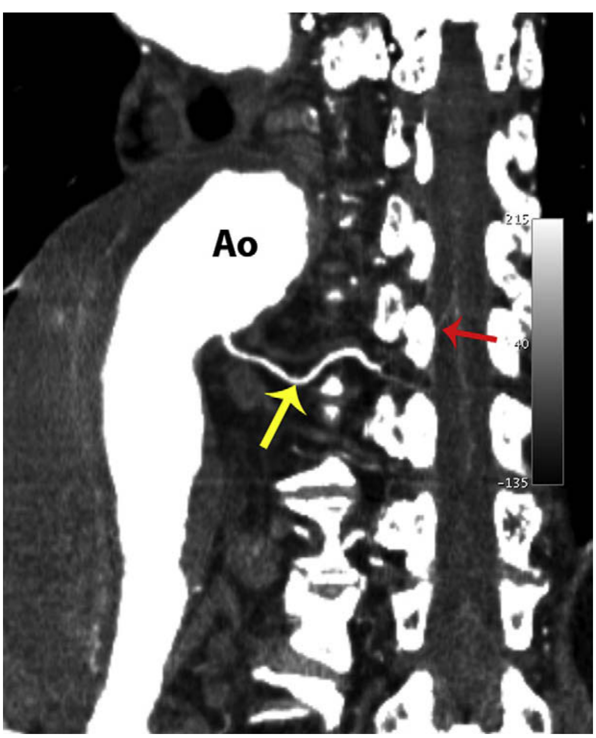

Figure 3 A 2D curved-MPR demonstrates connection from aorta to anterior spinal artery by the AKA, and its continuity. Yellow arrow points to intercostal artery, red arrow points to AKA and 'Ao' refers to aorta.

The AKA level comparison between proposed and standard methods showed a good agreement (weighted $k = 0.661$, 95% CI: 0.510–0.812), with 47 cases consensus (70.14%). In two (2.98%) cases, the AKA was identified by using the standard method, but not with the proposed method; in eight (11.9%) cases, the AKA was found by using the proposed method, but not with the standard method and, in 14 (20.89%) cases, the AKA was not found by using either method, which was considered as consensus.

Analysis of the AKA identification by the results from the proposed and standard methods showed a substantial agreement of 85.07% ($k = 0.636$, 95% CI: 0.428–0.844).

Discussion

The image processing application OsiriX (www.osirix-viewer.com) is dedicated to DICOM images produced by current medical equipment and runs on regular Mac OS X computers. It has been specifically designed for navigation and visualisation of multimodality and multidimensional images, including CT. It is available worldwide to be freely downloaded from the internet and is released under the GNU free software license, which grants recipients' rights to use, modify and redistribute copyrighted work.[5–7] It is possible to create personalised plugins that performs desired actions and also allows the user to perform measures that are useful in preoperative planning.

The absence of expensive software and hardware requirements makes this method readily available to clinicians. OsiriX proved to be easy to use, fast and has a short learning curve. During the data analysis, we also found that the proposed method could be learned and performed fast. The software is not meant to replace the workstations, but to provide another useful and flexible tool.

Knowledge of the AKA level has already been proved to have clinical importance in open and endovascular treatments of TAAA for prevention of spinal ischaemia.[1,11,20–23] In open surgery, precise preoperative location of AKA might be very useful to reduce the incidence of paraplegia/paraparesis in thoracic aortic disease, shortening clamp time by identifying intercostals arteries that need to be reimplantated.[11,12] In thoracic endovascular aortic repair, it may define the most appropriate landing zone, avoiding unnecessary coverage of important intercostal arteries.[24]

With current high-resolution CTA, identification of the AKA vessel is feasible noninvasively in many instances,[3,8,14,16,17,19] but because of its small size and a high variation in its location, it requires clinical knowledge and, so far, dedicated workstations. Although it is very important to differentiate the artery from a vein,[16,19] the proposed method of analysing the anterior anatomical space of the spinal cord avoids this mistake.

In this study, the proposed method for AKA identification, using OsiriX software, had a substantial recognition consensus of 85.07% compared to the standard method, using dedicated workstation and when applied to the same patients. A similar recognition percentage of 76.1% was obtained by using the proposed method which compares well with the analysis of the literature review (83.96%). The proposed method presents a higher prevalence of left AKA arteries (Fig. 3) consistent with the standard method and the analysis of the literature. Comparison of both methods showed good agreement of the AKA level when AKA is found with either method (weighted $k = 0.661$, 95% CI: 0.510–0.812). The AKA level distribution defined by the proposed method did not differ from the literature results. Employing this versatile tool, we realised that identification of the AKA could be quite easy from a standard set of contrast-enhanced CT scans.

Better understanding of normal anatomy could lead to more accurate comprehension of pathological anatomy, improving current knowledge of pathophysiology. This seems logical, and although the road ahead is still long, CTA scanner technology and computer processing power are improving fast. This article shows the feasibility of AKA location by using low-cost hardware and software, with standard contrast protocol, which, while broadening its use, also allows more centres to add important knowledge on this matter.

Although analysis of the 11 studies reviewed from the literature demonstrated the feasibility of noninvasive detection of AKA, the outcome in clinical terms of spinal cord injury was addressed only in six of them,[11,12,14,15,17,18] one of the possible reasons being the costs of hardware and software requirements limiting its spread. In those papers, a total of 184 patients who underwent open surgery or thoracic endovascular aneurysm repair (TEVAR) were analysed; of these, two cases developed neurological impairment.

Even though several authors claim that noninvasive preoperative recognition of AKA is a mainstay, the figures are yet too small to clarify its real impact on neurological outcome, and only three studies addressed this issue.[11,18,25] Future studies regarding clinical outcomes and preoperative AKA location are required to understand its importance in spinal cord ischaemia after aortic surgery. Studies should also evaluate AKA patency after open surgery or TEVAR using noninvasive AKA location, analysing clinical data and comparing outcomes in different treatments. It may become an important tool for the surgeon, with clinical relevance in spinal cord ischaemia prevention.

In conclusion, the AKA can be successfully delineated in a large percentage of patients using regular computers and the open-source software OsiriX and analysing 64-row CT scan data, which is already part of preclinical work-up in TAAA patients. Meanwhile, larger prospective studies will be needed to ascertain if preoperative knowledge of the AKA location will contribute to an effective strategy to avoid spinal cord ischaemia after thoracic and thoracoabdominal interventions.

Conflict of Interest/Funding

None.

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