



## Research article

# Low-tube-voltage CT assessment of Adamkiewicz artery: Precise comparison between 100-kVp- and 120-kVp protocols



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## ABSTRACT

**Purpose:** Preoperative identification of Adamkiewicz artery (AKA) for preventing postoperative spinal cord ischemia is still challenging because of its small diameter. Low-tube-voltage technique might improve the delineation of AKA due to its higher contrast enhancement and contrast-to-noise ratio (CNR). Our purpose was to evaluate the usefulness of low-tube-voltage CTA in visualization of AKA compared with the conventional voltage protocol on the condition with the same imaging parameters aside from tube voltage.

**Methods:** Eighty-three patients undergoing CTA for the evaluation of aorta were retrospectively included. All CTA was performed with 320-detector-row CT with the tube voltage of either 100-kVp (41 patients) or 120-kVp (42 patients). The CNR, CT value of aorta and objective image noise were assessed. Visualization of AKA was evaluated based on the continuity from aorta using the four-grade score by two independent reviewers. The estimated radiation dose (volumetric CT dose index) was also compared.

**Results:** The 100-kVp group showed significantly higher CNR and CT value than 120-kVp protocol ( $P = 0.010$  and  $< 0.001$ , respectively). The visual score was also significantly higher in 100-kVp group than in 120-kVp group ( $2.73 \pm 0.98$  and  $2.02 \pm 1.00$ , respectively;  $P = 0.002$ ). There was no significant difference on objective image noise and radiation dose between the groups ( $P = 0.24$  and  $0.72$ , respectively).

**Conclusion:** CTA with low-tube-voltage was significantly more sensitive for AKA visualization than conventional voltage protocol.

## 1. Introduction

The Adamkiewicz artery (AKA) is the dominant feeder of the spinal cord circulation at the thoracic level. Interruption of blood supply from the AKA is thought to be significant risk factor for spinal cord ischemia, a severe complication during aortic surgery and endovascular stent-grafting of the aorta resulting in paraplegia or paraparesis [1]. Because of this, preoperative identification of the AKA is of great interest for comprehension of spinal cord circulation and consequently reducing the risk of postoperative complication [2]. Despite improvements of CTA technique [3–9], visualization of the AKA is still challenging due to its small diameter (0.5–1.5 mm), its proximity to bony structures of the vertebrae, and complications from preexisting aortic abnormalities.

For visualization of the AKA, previous researchers have investigated

the optimal injection rate [3], dose of iodine concentration [3], injection method [4], timing of CT data acquisition [5], and method of CT data reconstruction [6]. These studies indicate that sufficient vascular enhancement and permissible noise level in the spinal canal; ie, increased contrast-to-noise ratio (CNR) in the spinal canal, can improve delineation of the AKA [7,8].

By lowering the tube voltage in CTA, the degree of vascular enhancement increases. This is because the x-ray output energy at lower voltages is closer to the K-edge of iodine (33.2 keV) [10]. In low tube voltage scanning, although radiation dose reduction is also expected, image noise increases, mainly due to higher absorption of low-energy photons in the human body. Hybrid iterative reconstruction techniques can eliminate this disadvantage [11]. With these techniques, the low tube voltage scan has been used to improve image quality and decrease

Abbreviations: AKA, Adamkiewicz artery; CNR, contrast-to-noise ratio

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the amount of contrast media and/or radiation dose [12]. In association with the update of the CT scanner in 2016, we introduced low tube voltage protocol in our institution. Recent reports have suggested protocols for CTA of different body parts such as the brain [13], head and neck [14], chest [15], and abdomen [16,17]. We selected the tube voltage of 100 kVp because in previous studies, 100-kVp protocol with iterative reconstruction showed improved contrast enhancement of aorta while maintaining image quality in chest and abdominal imaging [15,16].

To our knowledge, the effect of low tube voltage CTA in visualization of the AKA has rarely been with the same imaging parameters aside from tube voltage. The purpose of our study was to determine whether the low tube voltage protocol could improve visualization of the AKA compared with the conventional voltage protocol.

## 2. Material and methods

### 2.1. Study population

Our institutional review board approved this study. The requirement to obtain consent for retrospective medical record review was waived. From April 2016 to April 2017, we retrospectively selected 118 consecutive patients undergoing CTA using a 320-detector row CT scanner. Conventional tube voltage protocol (120 kVp) had been the standard method for CTA aortic evaluation in our institute. The low tube voltage protocol (100 kVp) began in July 2016. Inclusion criteria were as follows: undergoing a 100-kVp or 120-kVp CTA for evaluation of the aorta with the same CT scanner. Patients with aortic dissections ( $n = 35$ ) were excluded from this study because it was difficult to match the conditions of aortic dissection, such as size of the pseudo-lumen and position of the aortic flap, between the 2 protocols [9,18]. Images of poor quality due to metallic artifacts or severe motion were also excluded, but no case corresponded to this criterion. Finally, 83 patients (41 and 42 in the 100- and 120-kVp groups, respectively) were included. Indications for CTA were as follows: suspicion of aortic abnormality ( $n = 8$ ), follow-up for surgical or endovascular aortic grafting ( $n = 55$ ), preoperative evaluation of a known thoracic aortic aneurysm ( $n = 8$ ), and abdominal aortic aneurysm ( $n = 12$ ). We also retrieved patients' information such as age, sex, and body weight.

### 2.2. CT data acquisition and reconstruction

All CTAs were performed using a 320-detector row CT system (Aquilion ONE VISION Edition, Toshiba Medical Systems Corp., Otawara, Japan). The study and control groups were examined using the low tube voltage protocol with 100 kVp and conventional tube voltage protocol with 120 kVp, respectively. Aside from tube voltage, the same imaging parameters were applied as follows: reconstruction kernel, FC07; gantry rotation time, 0.5 s; detector configuration, 80 (detector number)  $\times$  0.5 mm (detector collimation); beam pitch, 0.813. The CT scanner was set to automatically modulate the mAs by using automatic exposure control; standard deviation of noise, 9. A 20-gauge intravenous catheter was placed in an antecubital vein in an upper limb of each patient. Contrast medium with an iodine concentration of 350 mg/mL (Iomeprol, Iomeron 350; Eisai, Tokyo, Japan) was used. A total volume of 70 mL contrast medium was administered at a rate of 4 mL/sec and was followed by flushing with 40 mL of physiological saline at the same injection rate using a double-head power injector (Dual Shot GX; Nemoto-Kyorindo, Tokyo, Japan). Synchronization between the flow of contrast agent and CT acquisition was achieved using a computer-assisted bolus tracking system (SureStart, Toshiba, Tokyo, Japan). The trigger threshold was set at 200 Hounsfield units (HU) for the ROI in the descending aorta and monitored by 2 radiology technologists. Ten seconds after the trigger, the scan was started. Data were acquired during a single breath hold in the head-to-foot direction. CT examination covered from the sternoclavicular junction to the groin.

Helical data were reconstructed by a hybrid iterative reconstruction algorithm (adaptive iterative dose reduction with 3D processing: AIDR 3D). This algorithm has four selectable noise reduction levels (weak, mild, standard and strong) and we selected the weak mode. Axial images were reconstructed with a section thickness of 1.0 mm at 1.0-mm intervals. For evaluation of radiation dose, the volumetric CT dose index displayed on the dose report of the CT scanner was recorded for each patient.

### 2.3. Objective image analysis

All objective image analysis was performed randomly and independently by 2 radiologist (A and B; 6 and 11 years of experience, respectively) using a commercially available workstation (AquariusNET; TeraRecon, Foster City, CA, USA). CT values of both the spinal cord and aorta were measured with manual placement of a circular ROI (25 mm<sup>2</sup> and 100 mm<sup>2</sup>, respectively) on 1.0 mm-thick an axial image. Reviewers respectively measured the CT value of aortic lumen at the level of 9th, 10th and 11th thoracic vertebra and the mean CT values were calculated. The CT value and standard deviation of spinal cord were also calculated as the mean values of three ROIs in three continuous slices at the level of 10th thoracic vertebra (Fig. 1). Objective image noise and contrast-to-noise ratio of the aorta were calculated for objective image analysis. Objective image noise was defined as the mean standard deviation of the ROI of the spinal cord. CNR of the aorta was computed as follows:

$$\text{CNR (aorta)} = \frac{\text{mean CT value (aorta)} - \text{mean CT value (spinal cord)}}{\text{mean standard deviation (spinal cord)}}$$

We used the CNR of the aorta as an indicator instead of the CNR of the AKA for several reasons. First, it was difficult to precisely measure the CT value of the AKA due to its small diameter. In contrast, CT value measurement in the aorta appeared to be stable. Second, in cases without visualization of the AKA, CNR computation was impossible. Third, the degrees of contrast enhancement of the aorta were considered to be similar to that of the intercostal or lumbar artery, from which the AKA, and subsequently the anterior spinal artery, arise [2,19]

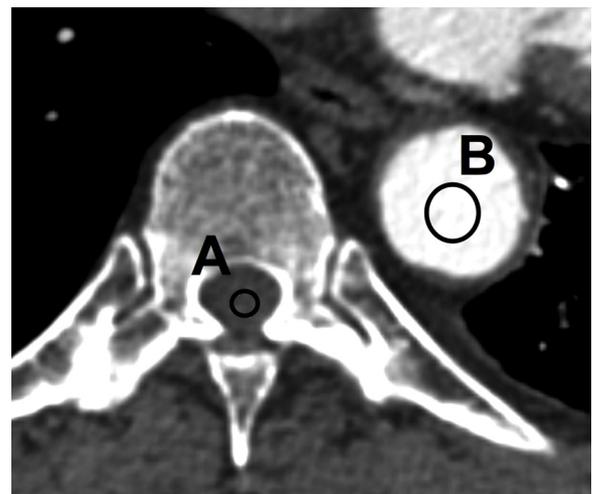
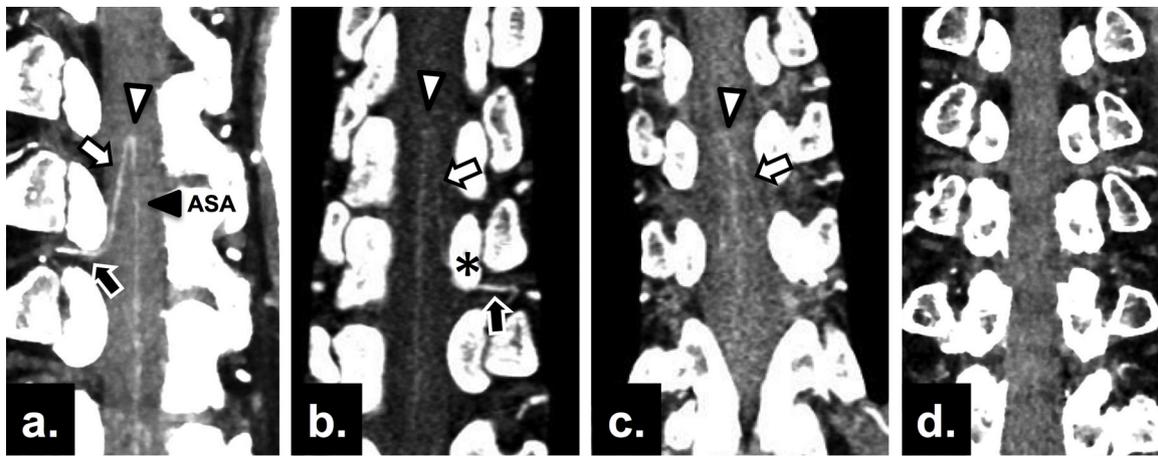


Fig. 1. An axial image at the level of the 10th thoracic vertebra demonstrating the circular regions of interest measured. Circles A and B show the ROIs of the spinal cord (25 mm<sup>2</sup>) and of the aorta (100 mm<sup>2</sup>), respectively.



**Fig. 2.** Visual scores of the AKA: oblique coronal multiplanar reconstruction images along the aorta.

a. Excellent visualization (score 4): proximal and distal portions of the RMA (black and white arrows) are totally visualized. Junction of the RMA and ASA forms a characteristic hair-pin curve (white arrowhead).

b. Good visualization (score 3): Characteristic hair-pin curve configuration (white arrowhead) is visualized. Continuity between the distal and proximal portions of the RMA (white and black arrows) is partially obscured due to the surrounding osseous structures and substantial intradural venous enhancement around the intervertebral foramen (asterisk). Branching level of the AKA can be identified.

c. Fair visualization (score 2): Although a characteristic hair-pin curve (white arrowhead) can be identified, continuity of the RMA (white arrow) is more obscure than score 3. Branching level of the AKA cannot be identified.

d. Poor visualization (score 1): AKA is not visible.

AKA, Adamkiewicz artery; ASA, anterior spinal artery; RMA, radiculomedullary artery.

#### 2.4. Visual assessment

The AKA was defined as a continuous vascular tract extending from an intercostal or lumbar artery via the anterior radiculomedullary artery to the anterior spinal artery by ascending to the midsagittal surface of the spinal cord and forming the characteristic “hairpin-curve” [9]. For visual assessment of the AKA, we used the 4-grade visualization score (Fig. 2) proposed by Utsunomiya et al. [3]. Briefly, 4 indicates excellent delineation with no structural discontinuity from the origin of the intercostal or lumbar artery through its posterior branch to the AKA and the anterior spinal artery; 3, good delineation with minimal discontinuity between the posterior branch of the intercostal or lumbar artery and AKA at the intervertebral foramen; 2, fair delineation indicating the characteristic hairpin-curve appearance of the AKA and anterior spinal artery; 1, poor image and no delineation of the AKA. All CT images were randomly evaluated by 2 radiologists who were blinded to the patients’ information. Each reviewer performed the initial evaluation independently and respectively describing the visual score of the AKA in 1.0-mm thick axial and oblique coronal multiplanar reconstruction images along the aorta. After the initial evaluation, reviewers discussed in cases where the reader’s assessment was differed and the final agreement was based on the consensus between the two reviewers. We treated an AKA visualization score of 3 or 4 as assessable for branching level. The level and side from which the AKA originated were also evaluated.

#### 2.5. Statistical analysis

Categorical variables were presented as relative frequencies (in percentages) and were compared using Fisher’s exact test. Continuous variables were presented as means with standard deviation (SD) and were compared using the Mann-Whitney U test. Effect size was also calculated as Cramer’s V: Cramer’s coefficient of association in categorical variables and as  $r$ : Pearson’s product moment correlation coefficient in continuous variables (0.10, small effect size; 0.30, medium effect size; 0.50, large effect size). In objective image analysis, the degree of agreement between the reviewers was determined by calculating the ICC. In visual assessment, interobserver agreement was

calculated with weighted Cohen’s kappa statistics (0.81–1.00, excellent; 0.61–0.80, good; 0.41–0.60, moderate; 0.21–0.40, fair; < 0.20, poor). A two-sided value of  $P < 0.05$  was considered significant. Effect size was calculated using statistical software (IBM SPSS Statistics for Windows, Version 21.0; IBM Corp., Armonk, NY, USA). Other analyses were conducted using the R statistical and computing software, version 3.3.1 (The R Foundation for Statistical Computing, Vienna, Austria).

### 3. Results

Patient demographics and clinical characteristics are listed in Table 1. There were no statistically significant differences between the groups. Diagnoses were as follows: abdominal aortic aneurysm ( $n = 37$ ), thoracic aortic aneurysm ( $n = 16$ ), thoracoabdominal aortic aneurysm ( $n = 3$ ), abdominal and thoracic aortic aneurysms ( $n = 6$ ), iliac aneurysm ( $n = 7$ ), visceral artery aneurysm ( $n = 2$ ), Takayasu’s arteritis ( $n = 2$ ), Behçet’s disease ( $n = 1$ ), arteriovenous malformation of the mediastinum ( $n = 1$ ), uretero-iliac artery fistula ( $n = 1$ ),

**Table 1**  
Patient demographics and clinical characteristics<sup>a</sup>.

	100-kVp group ( $n = 41$ )	120-kVp group ( $n = 42$ )	<i>P</i> value	Effect size
Age, y	71.2 ± 10.5	71.4 ± 12.5	0.830	<b>0.024<sup>b</sup></b>
Men, n (%)	33 (80.5)	31 (73.8)	0.603	<b>0.079</b>
Body weight, kg	63.4 ± 10.7	60.8 ± 13.3	0.402	<b>0.093</b>
Follow-up for surgical or endovascular aortic grafting	30	25	0.270	0.144
Extent of aortic replacement or endovascular repair, n (%)				
Ascending-descending aorta	5 (16.7)	6 (24.0)	0.501	<b>0.091</b>
Thoracoabdominal aorta	4 (13.3)	2 (8.0)	0.687	<b>0.085</b>
Infrarenal abdominal aorta	17 (56.7)	13 (52.0)	0.790	<b>0.047</b>
Peripheral artery	4 (13.3)	4 (16.0)	1.000	<b>0.038</b>

#### Note:

<sup>a</sup> Data are expressed as means ± standard deviation.

<sup>b</sup> Effect sizes less than 0.10 (small effect size) are in bold type.

**Table 2**  
CT value of aorta, objective image noise, CNR<sup>a</sup>.

	100 kVp (n = 41)	120 kVp (n = 42)	P value	ICC (P value; 95% CI)
Mean CT value of aorta (HU)				
Reader A	477.0 ± 114.6	397.8 ± 95.7	< 0.001 <sup>b</sup>	1 ( < 0.001; 1-1)
Reader B	477.1 ± 114.1	398.5 ± 96.3	< 0.001	
Objective image noise (HU)				
Reader A	17.0 ± 2.5	16.4 ± 1.8	0.238	0.80 ( < 0.001; 0.70-0.86)
Reader B	17.0 ± 2.6	16.4 ± 2.2	0.359	
CNR of aorta				
Reader A	25.8 ± 7.1	22.0 ± 6.5	0.010	0.95 ( < 0.001; 0.93-0.97)
Reader B	26.0 ± 7.9	22.2 ± 6.9	0.012	

**Note:** HU, Hounsfield unit, CNR, contrast-to-noise ratio, ICC, Intraclass correlation coefficient.

<sup>a</sup> Data are expressed as means ± standard deviation.

<sup>b</sup> Significant P values (< 0.05) are in bold type.

brachiocephalic artery thrombosis (n = 1), and peripheral artery disease (n = 2). There were no specific CTA findings in 4 patients.

There was no significant difference in the volumetric CT dose index between the 2 groups (P = 0.355). The mean volumetric CT dose index was 15.1 ± 2.9 mGy in the 100-kVp group and 15.0 ± 5.6 mGy in the 120-kVp group).

### 3.1. Objective evaluation

Results of objective image analysis are summarized in Table 2. The 100-kVp group showed significantly higher CT values and CNRs of the aorta than the 120-kVp group (P < 0.001 and P = 0.010 in reader A). There was no significant difference on objective image noise between the groups (P = 0.238 in reader A).

### 3.2. Visual assessment

Interobserver agreement was found to be excellent (kappa = 0.882, P < 0.001). Results of the visual assessment of the AKA are summarized in Table 3. In the 100-kVp group, the hair-pin curve and branching level of AKA were visually detectable on CTA in 37 of 41 (90.2%) and 23 of 41 (56.1%) studies, respectively. By contrast, in the 120-kVp group, the hair-pin curve and branching level were detectable in 28 of 42 (66.7%) and 14 of 42 (33.3%) studies, respectively. Visual scores of the AKA were significantly higher in the 100-kVp group than in the 120-kVp group (2.73 ± 0.98 and 2.02 ± 1.00, respectively; P = 0.002).

The branching level and the side of the intercostal or lumbar artery from which the AKA originated are summarized in Fig. 3. The AKA originated from the left side in 28 patients (75.7%) and from the level of the 9th to 12th intercostal arteries in 28 patients (75.7%).

## 4. Discussion

Preoperative CTA identification of the AKA is thought to be useful in the reduction of the risk of spinal cord ischemia during aortic surgery or

**Table 3**  
Results of visual assessment of the Adamkiewicz artery.

Visual score of the Adamkiewicz artery	100-kVp group (n = 41)	120-kVp group (n = 42)
4 = Excellent, n (%)	11 (26.8)	4 (9.5)
3 = Good, n (%)	12 (29.3)	9 (21.4)
2 = Fair, n (%)	14 (34.1)	13 (31.0)
1 = Poor, n (%)	4 (9.8)	16 (38.1)
Assessable	23 (56.1)	13 (31.0)

**Note:** Visual scores of 3 and 4 were treated as “assessable” in this study.

endovascular repair. There have been growing evidences to support the usefulness of AKA detection using CTA. Previous studies investigated the optimal timing of CT data acquisition [5], the infusion method of contrast media [3], and CT data reconstruction methods [6]. However, there are few reports on the investigation of tube voltage. Niihuhuis RJ et al. compared 120-kVp and 80-kVp CTA protocols in their subgroup analysis and referred to the usefulness of low tube voltage CTA [19]. However, their scanning parameters, such as rotation time and tube current, was different between the 120-kVp and 80-kVp groups, and detailed results were not shown, presumably due to poor statistical power. Shimoyama et al. compared 120-kVp and 70-kVp CTA protocols. However, their infusion protocol and reconstruction method were also different between the groups [20]. To our knowledge, investigation of different tube voltages with the other parameters maintained in visualization of the AKA, has not been reported. In this retrospective study, we investigated the effect of a low tube voltage protocol in visualization of the AKA. The results showed that the 100-kVp protocol was significantly superior to the 120-kVp protocol both in objective image analysis and visual assessment. There was no significant difference in radiation dose between the groups. The 100-kVp CTA protocol may be beneficial in visualization of the AKA.

From previous studies [21,22], the aorta should be more than 200 HU to obtain adequate vessel enhancement of the aorta and its main branches. However, according to other reports, the aorta needs to be more highly contrasted for visualization of the AKA (mean CT value range, 367–495 HU) [3,7,9]. Actually, intra-arterial CTA has drastically improved AKA detection rates (94%–100%) due to improved enhancement of the aorta [4]. To enhance the aorta strongly in CTA, previous studies have suggested infusion protocols with contrast medium of a higher iodine concentration and at a faster injection rate. In this study, the mean CT value of the aorta in the 100-kVp group was 477 HU (about 20% higher than that in the 120-kVp group). This result implies the usefulness of a low tube voltage technique in obtaining stronger aortic enhancement.

In comparison with the 120-kVp group, the CNR of the aorta was significantly higher in the 100-kVp group, while there was no significant difference in image noise between the groups. Based on previous studies [12,17], we believe the increase in image noise in the low tube voltage protocol may be less concerning in iodine contrast-filled vessels than in soft tissues such as liver or muscle. This is because contrast enhancement can eliminate imaging noise in highly enhanced tissues. Also, the same automatic exposure control setting used in the 2 groups might contribute to maintaining the image noise level.

Previous studies have indicated that increased CNR in the spinal canal might improve delineation of the AKA [23]. Although we could not directly measure the CNR of the AKA, the CNR of the aorta should reflect the CNR in the spinal canal because we calculated the CNR of the aorta from the noise of the spinal cord. Our study demonstrates that higher CNRs in the spinal canal might be achieved using the 100-kVp protocol.

In our study using 4-graded visualization criteria, the branching level of AKA was assessable in 56.1% of the patients using the 100-kVp protocol. This detection rate did not appear to be as high as that of previous studies (60%–100%) at first glance. There are some possible reasons. First, the study populations and evaluation criteria were not identical among studies; for example, Shimoyama et al. used 6-point scoring system [20]. Second, our study used a total amount of 70 ml of contrast medium with an iodine concentration of 350 mg/mL because the population of our study underwent CT not to detect AKA but to evaluate the aortic diseases. Seventy ml was less than that of previously reported; for example, Nishida et al. and Machida et al. used 100 ml of contrast medium with an iodine concentration of 370 mg/mL [6,8]. The low amount of contrast medium should influence the detection rate. Therefore, simple comparison of the detection rate with the previous reports was difficult. Also, our purpose was to clarify the effect of the low tube voltage protocol in AKA visualization by unifying parameters

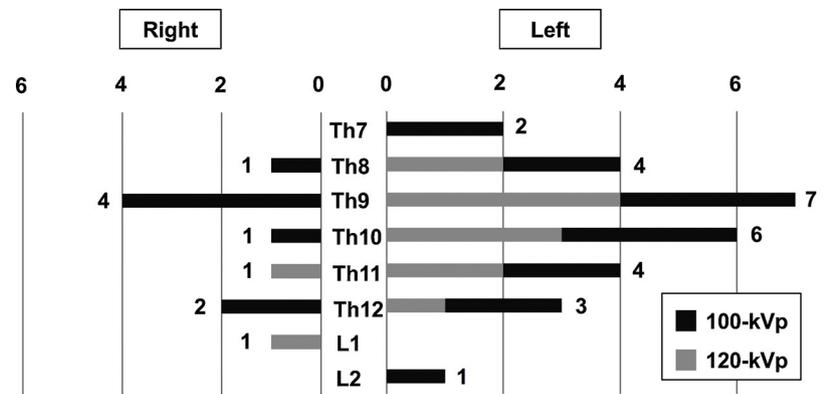


Fig. 3. Distribution of originating levels of the AKA through the thoracic and lumbar segments in 35 assessable patients. Th, thoracic spine; L, lumbar spine.

other than tube voltage.

Although radiation dose reduction in the 100-kVp group was expected according to the results of previous studies [13–17], there was no significant difference in radiation dose between our 2 groups. In a previous phantom study [24], when automatic exposure control was used under the same standard deviation (SD) setting, the radiation dose difference tended to be small between the 100-kVp and 120-kVp settings. Automatic exposure control manages the tube current to maintain noise level and induces the radiation dose increase in the low tube voltage protocol.

Our study had some limitations. First, the study populations did not completely match between the 2 trial protocols because of the retrospective nature of the study. Aortic surgery and stent graft placement may influence visualization of the AKA; however, there was no significant difference between the ratio of the treated aortic segments. Moreover, there was no significant difference between the groups with regard to the other parameters as keys for visualization of the AKA in previous reports. Therefore, we believe that any difference between the 2 groups should be small. Second, the ranges and mean values of body weight in our patients were smaller than those in North American and European individuals [25]. In larger-sized patients, more contrast medium should be used for better visualization of the AKA. Third, validation of AKA identification was not obtained. Selective spinal angiography is the gold standard to detect the AKA. However, this technique is more invasive than CTA and carries the potential risk of aortic dissection or an ischemic event of the spinal cord, especially in patients with a large aneurysm of the thoracic or abdominal aorta. Because of this, routine spinal angiography is not a clinically acceptable method of validation of the AKA and is no longer performed in our institution. In addition, the AKA shape and distribution level assessed in this study were in agreement with the previous literature [1,3]. Finally, in this study, the same amount of contrast medium was used between the 2 groups. In low tube voltage scanning, dose reduction of contrast medium is expected, and future study should focus on the optimal amount of contrast medium. In previous report, patients with aortic aneurysm undergoing endovascular repair or surgery have a higher prevalence of chronic kidney disease (31%) [26]. These patients have a higher risk of contrast medium-induced nephropathy. In these patients, a reduction in the amount of contrast medium is highly desirable, and a lower tube voltage (80-kVp or 70-kVp) protocol may be more useful. However, lowering the tube voltage increases image noise. Previous studies have suggested that 80-kVp scans were not appropriate for larger-sized patients, and 100-kVp scans were better suited for large patients [12,27]. In more recent studies, a model-based iterative reconstruction method improved delineation of the anterior spinal artery or Adamkiewicz artery in the 120-kVp protocol [6,8]. Application of this technique in future studies may be useful in improving visualization of the AKA in the low tube voltage protocol.

## 5. Conclusions

In this retrospective study, low tube voltage CTA improved identification of the AKA compared with conventional tube voltage CTA. By lowering the tube voltage, the CNR of the aorta increased while objective image noise in the spinal canal was maintained at a permissible level. The 100-kVp CTA protocol may be beneficial in visualization of the AKA.

## Conflict of interest

None.

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