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ORIGINAL PAPER

Aortic CT angiography using the double region of interest timing bolus technique: feasibility of 80 kVp scanning in lean patients

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Abstract
To investigate the feasibility of aortic computed tomography angiography (CTA) performed at 80 kVp in lean patients using the double region of interest timing bolus (DRTB) technique compared to 100 kVp scanning. This study was approved by the institutional ethics committee, and all patients provided written informed consent. We prospectively included 165 patients from July 2018 to February 2019. We used an 80 kVp protocol when the maximal tube current did not exceed the limit using automatic exposure control; otherwise, 100 kVp was selected. The scan parameters for aortic CTA were determined from the test scan data. Enhancement at six points of the aortoiliac arteries and noise at the bifurcation level were measured. We compared the enhancement and signal to noise ratio (SNR) using Student's *t*-test. The tube voltage was 80 kVp in 87 patients (53%). The enhancement of the aortoiliac arteries was significantly higher (449.3 ± 77.8 vs 378.7 ± 53.1 HU, $p < 0.0001$) and the SNR was similar (42.4 ± 11.1 vs 40.0 ± 10.6, $p = 0.17$), and the amount of contrast medium was lower (33.0 ± 2.5 vs 41.8 ± 3.3 ml, $p < 0.001$) in the 80 kVp group compared to the 100 kVp group. Reducing the tube current to 80 kVp could decrease the amount of contrast medium used compared to the 100 kVp protocol, while maintaining image quality, for aortic CTA using the DRTB technique.

Keywords Aorta · Computed tomography angiography · Contrast medium · Timing bolus technique

Introduction

Contrast medium injection is necessary to perform computed tomography angiography (CTA) of the aorta. As patients with aortic disease, such as aneurysm or dissection, frequently also have renal dysfunction, the amount of contrast medium should be kept as low as possible to prevent contrast-induced nephropathy [1]. With advances in CT technology, low-tube voltage and dual-energy scanning have been applied to reduce the amount of contrast medium used in aortic CTA [2, 3]. Recently, the double region of interest timing bolus (DRTB) technique has been introduced as a novel method to perform CTA of the aorta with a reduced amount of contrast medium [4]. The flow of the aorta could be estimated by placing two regions of interest (ROIs) at the ascending and descending aorta during the timing bolus scan. A very short bolus injection of 9 s is feasible by synchronizing the scan speed to the flow of the aorta. Although aortic CTA was performed with 40 ml of contrast medium in this previous study, the tube voltage was 100 kVp in all patients [4]. We hypothesized that further reduction of contrast medium could be achieved by reducing the tube voltage to 80 kVp in lean patients. Therefore, the present study was performed to investigate whether aortic CTA performed with an 80 kVp scan protocol in lean patients using the DRTB technique could reduce the amount of contrast medium, while maintaining the enhancement and image quality compared to 100 kVp scans.

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Materials and methods

Patients

The local ethics committee approved this prospective study, and all patients provided written informed consent (UMIN Clinical Trials Registry 000030497). The initial study population consisted of 183 patients who were clinically indicated for aortic CTA between July 2018 and February 2019 (Fig. 1). The inclusion criteria were as follows: postoperative state of the aorta (n = 97), back pain (n = 37), aortic aneurysm (n = 29), and aortic dissection (n = 20). We excluded the following patients: unable to give consent due to emergency treatment (n = 10), declined to participate (n = 4), and protocol deviation (n = 4). Therefore, the final study population consisted of 165 patients (129 men [mean age ± standard deviation (SD), 72.9 years ± 9.3; range 35−94 years] and 36 women [mean age ± SD, 73.3 years ± 6.7; range 59−84 years]). A 20-gauge catheter was placed at the right antecubital vein and contrast medium was injected using a power injector (Dual Shot GX7; Nemoto Kyorindo, Tokyo, Japan). A spiral flow tube (Nemoto spiral flow; Nemoto Kyorindo, Tokyo, Japan) was used as a connecting tube for saline flush [5].

CT data acquisition: DRTB method

All scans were performed using a 64-row CT (Somatom Definition AS+; Siemens Healthineers, Forchheim, Germany). First, a non-enhanced scan from the chest to pelvis was performed with the following parameters: tube voltage, 80 or 100 kVp; reference mAs, 600 or 340 mAs; collimation, 64 × 0.6 mm; gantry rotation time, 500 ms; helical pitch 0.85. The tube voltage was set to 80 kVp when the maximal tube current did not exceed the limit using automatic exposure control with a helical pitch of 0.85. Otherwise, a 100 kVp scan was performed. The length of the aortic root to the top of the aortic arch (Fig. 2a, L0), chest scan length (Fig. 2a, L1), and the abdominal scan length (Fig. 2a, L2) were recorded [4].

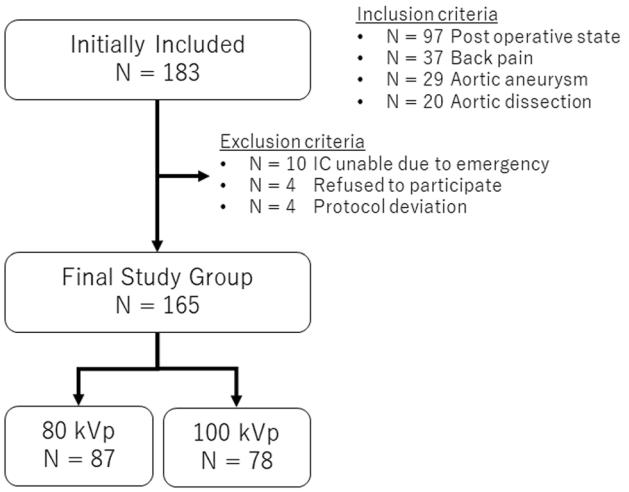

Fig. 1 Patient flow chart. A total of 183 patients were initially included. After excluding 18 patients, 165 patients were included in the final study group. IC, informed consent

A timing bolus scan was performed at the level of the aortic root with a tube voltage of 80 or 100 kVp and a current of 60 or 30 mAs (Fig. 2a). We used 7 and 9 ml of iopamidol 370 mg iodine/ml (Iopamiron 370; Bayer, Osaka, Japan) and a 30 ml saline flush, with an injection speed of 3.6 and 4.5 ml/s when the tube voltage was 80 and 100 kVp, respectively (Table 1). The monitoring scan started 12 s after injection of the contrast medium with an interval of 1 s. The reconstructed image was transferred to a workstation (Synapse VINCENT, ver 5.2; Fujifilm Medical, Tokyo, Japan) for time density curve analysis. Two ROIs were placed at the ascending and descending aorta (Fig. 2b), respectively, and the difference in time to peak between the two curves (Fig. 2c, T1) and the time to peak of the descending aorta (Fig. 2c, T2) were recorded. The flow of the thoracic aorta (F1) was estimated as follows (Fig. 3):

$$F1 = \frac{2 \times L0}{T1}$$

As the flow of the abdominal aorta (F2) is slower than the thoracic aorta [6], we estimated F2 as follows:

$$F2 = 0.6 \times F1$$

The peak enhancement of the descending aorta was also recorded. We defined ΔDesc as peak enhancement at the descending aorta during test injection. The total amount of contrast medium and the injection speed during aortic CTA acquisition was adjusted by the ΔDesc value ranging from 30 to 45 ml and 3.2 to 5.0 ml/s, respectively, followed by a 50 ml saline flush (Table 1). This amount was determined based on the results of a previous study to achieve a target enhancement of 380 Hounsfield units (HU) and a signal to noise ratio (SNR) of 40 [4]. The enhancement of 80 kVp acquisition was estimated by a phantom study (data not shown). The scan start timing was set as T2 and the helical pitch was adjusted to scan the aorta with the following scan time:

$$Scantime = \frac{L1}{F1} + \frac{L2}{F2} + C$$

where C is a constant to adjust for abdominal stents (C = 1 s) and abdominal aortic aneurysms (C = 1 s for diameter 40–49 mm, C = 2 s for diameter ≥ 50 mm) [4].

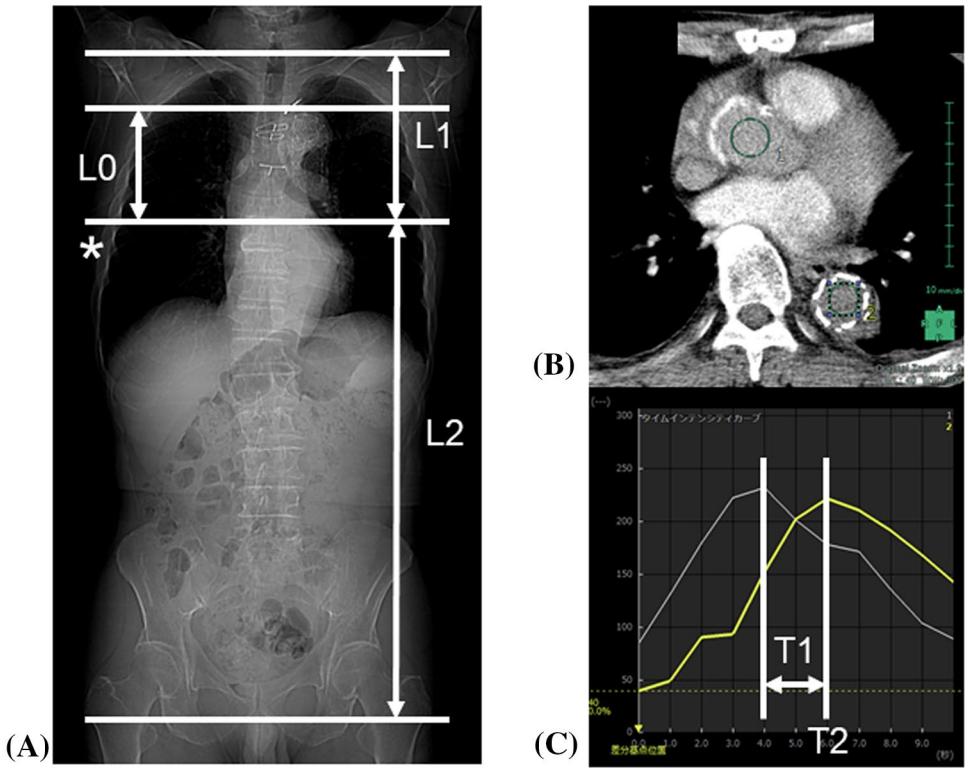

Fig. 2 Timing bolus scan was performed at the aortic root level (**a**, asterisk). Time density curves at the ascending and descending (**b**) aorta were drawn (**c**). The distance from the aortic root to the top of the aortic arch (**a**, L0), chest scan length (**a**, L1), and abdominal scan length (**a**, L2) were measured on non-enhanced images. The difference in time to peak between the ascending and descending aorta (**c**, T1), and the time to peak of the descending aorta (**c**, T2) were recorded using the time density curve. ROI, region of interest

Table 1 Contrast medium injection protocol

	80 kVp			100 kVp		
	Amount (ml)	Speed (ml/s)	N	Amount (ml)	Speed (ml/s)	N
Test injection	7	3.6	87	9	4.5	78
Main bolus						
ΔDesc < 100 HU	36	4.0	22	45	5.0	27
ΔDesc 100–175 HU	33	3.6	48	40	4.5	49
ΔDesc > 175 HU	30	3.2	17	36	4.0	2

ΔDesc peak enhancement at the descending aorta during test injection

Finally, a delayed phase scan was performed with the same scan parameters of the plain scan. The scan initiated 16 s after the end of the arterial phase.

The CT dose index and dose length product was recorded. The effective dose was calculated using a conversion coefficient for the abdomen ($\kappa = 0.015$ mSv mGy^{-1} cm^{-1}).

Objective analysis

One reader (13 years of experience) performed the objective analyses. Circular ROIs were drawn at six locations on the aortoiliac arteries: the ascending and descending aorta at the level of the aortic root, the aortic arch, abdominal aorta at the level of the celiac artery origin and just above the bifurcation, and the common femoral arteries. The enhancement of the bilateral common femoral arteries was averaged. The SD of the ROI at the bifurcation level of the aorta was determined as the image noise. SNR was calculated as aortoiliac attenuation divided by the image noise.

Subjective analysis

Two radiologists (13 and 4 years of experience) independently assessed the image quality using a four-point scale for uniformity, noise, and overall quality (uniformity: 4 = excellent with no difference between thoracic aorta and iliac arteries, 3 = slight difference between thoracic aorta and iliac arteries, 2 = apparent difference between thoracic aorta and iliac arteries but still enhanced, 1 = nondiagnostic with no proximal or distal enhancement; noise: 4 = excellent with minimal image noise, 3 = little image noise present, 2 = image noise present but still diagnostic, 1 = nondiagnostic due to excessive image noise; overall: 4 = excellent, 3 = good, 2 = fair, 1 = nondiagnostic). In the case of a

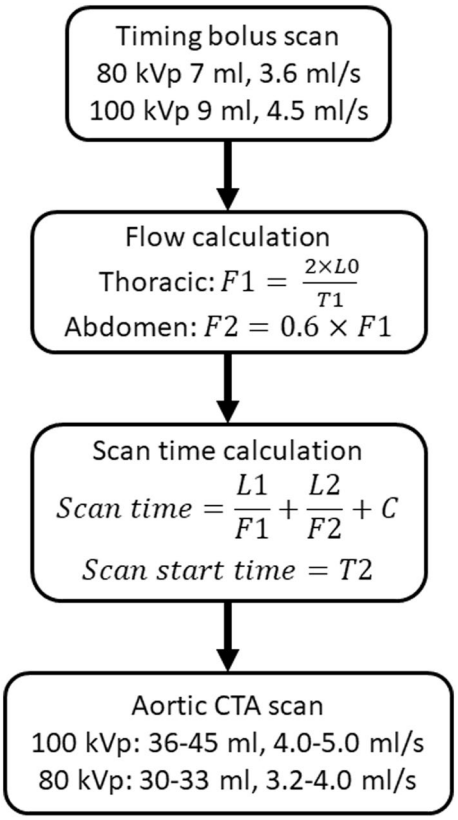

Fig. 3 Flowchart shows DRTB technique for CT angiography. *F1* = flow in thoracic aorta, *F2* = flow in abdominal aorta, *L0* = length from aortic root to arch, *L1* = chest scan length, *L2* = abdominal scan length, *T1* = transit time, *T2* = time to peak of descending aorta, *C* = adjustment constant (after endovascular aortic repair, *C* = 1 s; for abdominal aortic aneurysm [AAA] 40–49 mm, *C* = 1 s; for AAA ≥ 50 mm, *C* = 2 s; otherwise, *C* = 0 s). We limited the scan time between 10 to 20 s

discrepancy between the readers, the final score was determined by consensus. The axial image and three-dimensional image, including volume rendering and maximal intensity projection images, were used in the evaluation. All image datasets were shown with random blinding of the scanning parameters to prevent recall bias.

Statistical analysis

Continuous variables are shown as means ± SD and categorical variables as number unless otherwise indicated. Student's *t* test was used to compare continuous variables. Fisher's exact test or the chi-square test was used to compare categorical variables. Pearson's correlation analysis was used to investigate the relationships between body weight and aortoiliac enhancement or SNR. Interobserver agreement in subjective analysis was given by Cohen's kappa static [7], categorized as poor (κ < 0.20), fair (κ = 0.21–0.40), moderate (κ = 0.41–0.60), good (κ = 0.61–0.80), very good (κ = 0.81–0.90), or excellent (κ ≥ 0.91).

Power analysis was performed to determine the appropriate sample size. The primary endpoint was the non-inferiority of the mean SNR of the aortoiliac arteries between the 80 and 100 kVp scanning protocols. Based on the results of a previous study [4], the SNR was estimated to be 40. The effect size would be 0.45 with a mean SNR difference of 5 and an SD of 11. Power analysis showed that at least 79 patients in each group were needed with 0.80 power and a type 2 error of 0.05. We finally included 165 patients because slightly more patients were undergoing an 80 kVp scan than a 100 kVp scan. The power achieved according to post-hoc analysis was 0.82.

All statistical analyses were performed using JMP software (ver 12.0.1; SAS, Cary, NC). In all analyses, $p < 0.05$ was taken to indicate statistical significance.

Results

Patient characteristics

Slightly more patients underwent an 80 kVp scan (n = 87, 53%) than 100 kVp scan (n = 78, 47%) (Table 2). The proportions of male and obese patients were significantly higher ($p < 0.01$) in the 100 kVp group than the 80 kVp group, because low-tube voltage scan was not feasible in obese patients due to increased noise. Approximately 40% and 20% of the patients had aortic aneurysm and dissection, respectively. About half of the patients had previously undergone surgical treatment of the aorta and 36% of the patients had undergone stent placement. There was no significant difference in the proportion of aortic treatment between the two groups.

Scan characteristics

The mean contrast medium volume and injection speed during aortic CTA were 37.2 ± 5.3 ml and 4.1 ± 0.6 ml/s, respectively, in all patients (Table 2). The injected contrast medium volume (33.0 ± 2.5 vs 41.8 ± 3.3 ml, $p < 0.001$) and injection speed (3.6 ± 0.3 vs 4.7 ± 0.3 ml/s, $p < 0.001$) were significantly lower in the 80 kVp protocol than the 100 kVp protocol. The scan start time and scan duration were not significantly different between the groups. The mean CT dose index (6.2 ± 1.1 vs 9.7 ± 1.5 mGy, $p < 0.001$) and effective dose (5.7 ± 1.1 vs 9.1 ± 1.9 mSv, $p < 0.001$) were significantly lower in the 80 kVp group than the 100 kVp group.

Table 2 Patient and scan characteristics

	All patients	Subgroup by tube voltage		*P*
		80 kVp	100 kVp	
Number of patients	165	87	78	
Male	129 (78)	61 (70)	68 (87)	0.009*
Age (years)	73.0 ± 8.8	73.7 ± 8.1	72.3 ± 9.5	0.29
Body weight (kg)	59.8 ± 10.7	54.0 ± 8.0	66.3 ± 9.6	< 0.0001*
BMI (kg/m^2)	22.9 ± 3.2	21.3 ± 2.7	24.7 ± 2.7	< 0.0001*
Aneurysm				
Thoracic	30 (18)	16 (18)	14 (18)	1.00
Abdominal	31 (19)	12 (14)	19 (24)	0.11
Dissection				0.10
None	131 (79)	36 (77)	33 (70)	
Stanford A	3 (2)	0 (0)	9 (19)	
Stanford B	31 (19)	11 (23)	5 (11)	
Aortic replacement				0.88
Ascending	21 (13)	11 (13)	10 (13)	
Arch	35 (21)	21 (24)	14 (18)	
Descending	0 (0)	0 (0)	0 (0)	
Abdominal	24 (15)	10 (11)	14 (18)	
Stent placement				0.63
TEVAR	33 (20)	18 (21)	15 (19)	
EVAR	27 (16)	13 (15)	14 (18)	
Contrast medium (ml)	37.2 ± 5.3	33.0 ± 2.5	41.8 ± 3.3	< 0.001*
Injection speed (ml/s)	4.1 ± 0.6	3.6 ± 0.3	4.7 ± 0.3	< 0.001*
Scan start time (s)	21.6 ± 4.9	21.8 ± 4.9	21.5 ± 5.0	0.69
Scan duration (s)	13.9 ± 3.2	14.0 ± 3.2	13.9 ± 3.2	0.76
CTDI (mGy)	7.9 ± 2.2	6.2 ± 1.1	9.7 ± 1.5	< 0.001*
Effective dose (mSv)	7.3 ± 2.3	5.7 ± 1.1	9.1 ± 1.9	< 0.001*

Data are mean ± SD or N (%)

BMI body mass index, *CTDI* computed tomography dose index, *EVAR* endovascular aneurysm repair, *TEVAR* thoracic endovascular aneurysm repair

*Statistically significant, $p < 0.05$

Objective analysis

The mean enhancement of the aortoiliac arteries for all patients was 415.9 ± 75.8 HU with an SNR of 41.2 ± 11.1 (Table 3). The mean enhancement was significantly higher in patients scanned at 80 kVp than at 100 kVp (449.3 ± 77.8 vs 378.7 ± 53.1, $p < 0.0001$). The enhancement of the common femoral artery was 20% lower than the enhancement of the aorta. The image noise was higher in the 80 kVp group than the 100 kVp group (11.0 ± 2.2 vs 9.9 ± 2.0, $p < 0.0004$), but SNR did not differ between the two groups (42.4 ± 11.4 vs 40.0 ± 10.6, $p = 0.17$).

A significant negative correlation was observed between aortoiliac enhancement and body weight (Fig. 4). The relationship was stronger in the 80 kVp group than the 100 kVp group ($R^2 = 0.16$, $p < 0.0001$ and $R^2 = 0.11$, $p < 0.003$, respectively). A similar negative relationship was observed between the SNR and body weight ($R^2 = 0.26$, $p < 0.0001$ and $R^2 = 0.23$, $p < 0.0001$, respectively). All patients showed enhancement over 240 HU and SNR over 22.5. Optimal enhancement of the aortoiliac arteries was achieved even with an injected contrast medium volume of 30 ml in 17 patients (Fig. 5).

Subjective analysis

Interobserver agreement on subjective image quality was classified as good or very good: uniformity, $\kappa = 0.85$; noise, $\kappa = 0.71$; overall, $\kappa = 0.80$. The uniformity (3.7 ± 0.7 vs 3.7 ± 0.6, $p = 0.81$) and image noise (3.9 ± 0.3 vs 3.9 ± 0.3, $p = 0.69$) were similar between the 80 and 100 kVp protocols, with no significant difference in overall image quality (3.8 ± 0.6 vs 3.8 ± 0.4, $p = 0.78$) (Table 4).

We also assessed subjective image quality by the status of the patient (aneurysm, dissection, and post-surgery). Uniformity was significantly lower at post-surgery status (3.5 ± 0.8 vs 3.8 ± 0.8, $p = 0.02$). Image noise was significantly higher when dissection was present (3.8 ± 0.4 vs 4.0 ± 0.2, $p = 0.01$). The overall image quality was significantly lower when aneurysm (3.6 ± 0.7 vs 3.8 ± 0.4, $p = 0.003$) or dissection (3.6 ± 0.6 vs 3.8 ± 0.5, $p = 0.01$) was present and at post-surgery status (3.7 ± 0.6 vs 3.8 ± 0.4, $p = 0.02$) (Table 4).

Discussion

The present study showed that the amount of contrast medium during CTA of the aorta could be reduced by performing an 80 kVp scan in lean patients. Even injection of 30 ml of contrast medium was sufficient to achieve optimal aortic enhancement in 10% of the patients. Although the degree of image noise was slightly higher in the 80 kVp images than the 100 kVp images, the higher enhancement resulted in similar SNR between the 80 and 100 kVp acquisition protocols. There was no difference in subjective image quality between the two protocols. Even when the radiation exposure is reduced, use of iterative reconstruction technique would help to maintain the image quality [8, 9]. Although the subjective image quality decreased when aneurysm or dissection was present and at post-operative state, the difference in subjective image quality score was small (≤ 0.3).

A previous study employing the DRTB technique used 40 ml of contrast medium in all patients [4]. Therefore, 6 of 126 patients were excluded from the study due to low

Table 3 Enhancement and signal to noise ratio of the aorta

	All patients	Subgroup by tube voltage		*P*
		80 kVp	100 kVp	
Aorta				
Ascending	413.6 ± 95.0	450.2 ± 98.2	372.7 ± 72.3	< 0.0001*
Arch	447.0 ± 80.8	479.9 ± 83.7	410.9 ± 59.4	< 0.0001*
Descending	443.3 ± 81.1	478.2 ± 86.4	404.5 ± 58.8	< 0.0001*
Celiac	424.5 ± 85.1	462.9 ± 88.4	381.7 ± 56.4	< 0.0001*
Bifurcation	419.8 ± 92.9	453.7 ± 100.7	382.0 ± 65.7	< 0.0001*
Common femoral	346.8 ± 98.6	370.9 ± 110.7	320.0 ± 75.2	0.0008*
Average	415.9 ± 75.8	449.3 ± 77.8	378.7 ± 53.1	< 0.0001*
Image noise	10.5 ± 2.1	11.0 ± 2.2	9.9 ± 2.0	0.0004*
SNR				
Ascending	41.0 ± 12.3	42.5 ± 13.1	39.3 ± 11.3	0.09
Arch	44.2 ± 11.0	44.9 ± 10.9	43.4 ± 11.2	0.37
Descending	43.8 ± 11.1	44.8 ± 11.3	42.6 ± 10.8	0.20
Celiac	42.0 ± 11.6	43.6 ± 12.3	40.3 ± 10.6	0.06
Bifurcation	41.8 ± 12.8	43.0 ± 13.6	40.5 ± 11.9	0.21
Common femoral	34.7 ± 12.9	35.2 ± 13.6	34.0 ± 12.0	0.55
Average	41.2 ± 11.1	42.4 ± 11.4	40.0 ± 10.6	0.17

Data are mean ± SD

SNR signal to noise ratio

*Statistically significant, $p < 0.05$

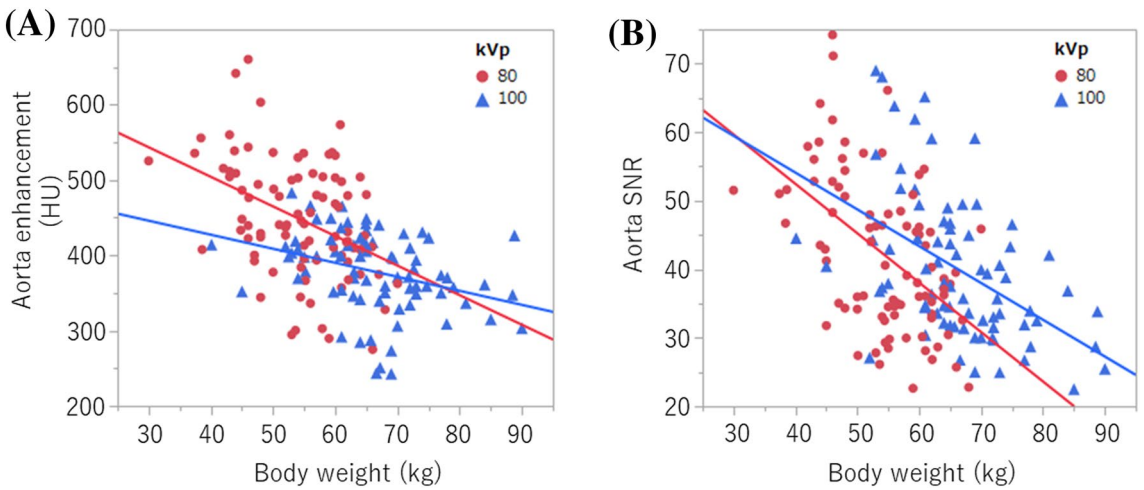

Fig. 4 Scatter plot of aortic enhancement (**a**) and SNR (**b**) against body weight. Circular and triangular plots represent 80 and 100 kVp scans, respectively. Bold lines represent linear regression. Significant negative correlations were observed between aortic enhancement and body weight (80 kVp: $R^2 = 0.16$, $p < 0.0001$; 100 kVp: $R^2 = 0.11$, $p < 0.003$) and between SNR and body weight (80 kVp: $R^2 = 0.26$, $p < 0.0001$; 100 kVp: $R^2 = 0.23$, $p < 0.0001$). SNR, signal to noise ratio

peak enhancement during the timing bolus scan, while the aortic enhancement exceeded 500 HU in several patients. The optimal amount of contrast medium to achieve target enhancement could be estimated by the peak enhancement of the timing bolus data [10, 11]. Therefore, aortic CTA using the DRTB technique could be performed in all patients included in the study. However, the enhancement of the aorta tended to be higher in lean patients, especially when a tube voltage of 80 kVp was used. In addition, the enhancement of the iliac arteries was lower than that of the aorta. As the flow of the aorta is estimated using data for the thoracic region, there may be a discrepancy between the estimated and actual flow of the abdominal aorta. Parameters such as body surface area, cardiac output, and age are correlated

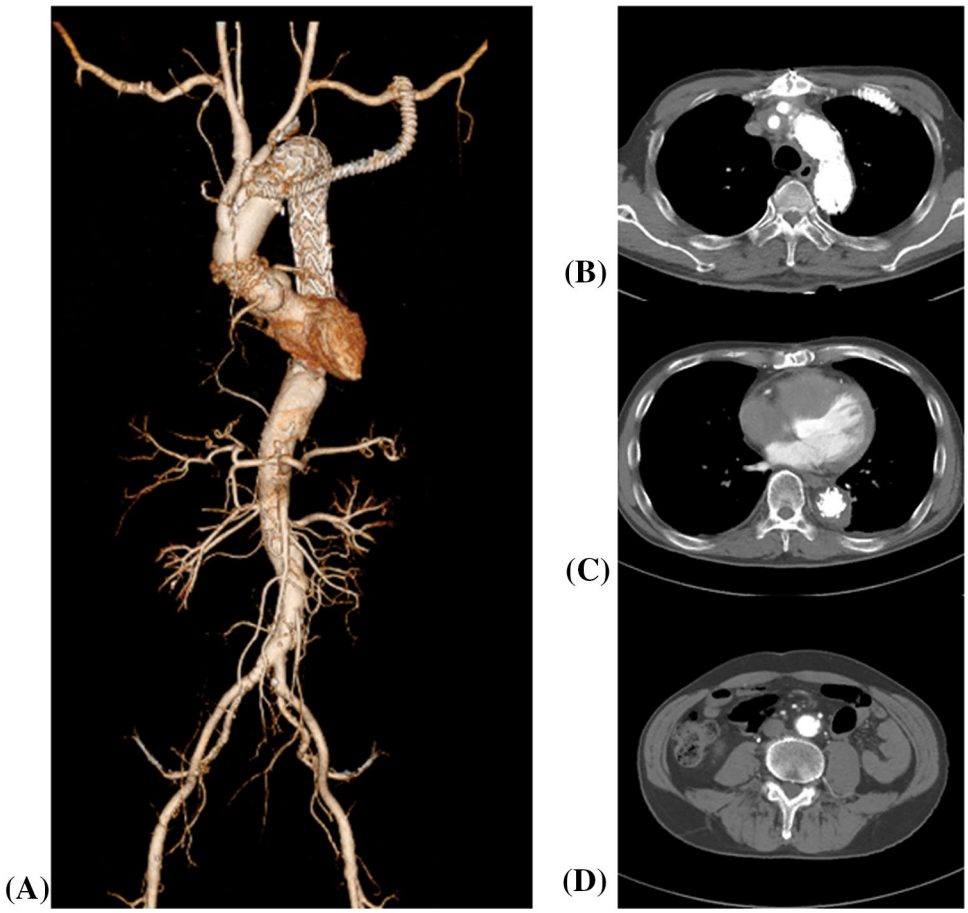

Fig. 5 A 71-year-old male patient with postoperative Stanford A dissection. Three-dimensional (**a**) and axial arterial phase angiograms **b**–**d** show optimal enhancement of the aortoiliac arteries. An 80 kVp scan was performed with 30 ml of contrast medium injected at 3.2 ml/s. The mean aortoiliac enhancement was 480 HU with a signal to noise ratio of 48.5

Table 4 Subjective image quality

	80 kVp	100 kVp	*P*
Uniformity	3.7 ± 0.7	3.7 ± 0.6	0.81
Image noise	3.9 ± 0.3	3.9 ± 0.2	0.69
Overall	3.7 ± 0.6	3.8 ± 0.4	0.78
	Aneurysm	No aneurysm	*P*
Uniformity	3.6 ± 0.8	3.7 ± 0.6	0.21
Image noise	3.9 ± 0.3	3.9 ± 0.2	0.50
Overall	3.6 ± 0.7	3.8 ± 0.4	0.003*
	Dissection	No dissection	*P*
Uniformity	3.5 ± 0.8	3.7 ± 0.6	0.10
Image noise	3.8 ± 0.4	4.0 ± 0.2	0.01*
Overall	3.6 ± 0.6	3.8 ± 0.5	0.01*
	Post-surgery	No surgery	*P*
Uniformity	3.5 ± 0.8	3.8 ± 0.6	0.02*
Image noise	3.9 ± 0.3	3.9 ± 0.2	0.23
Overall	3.7 ± 0.6	3.8 ± 0.4	0.02*

Data are mean ± SD

*Statistically significant, $p < 0.05$

with enhancement in the lower extremity CTA, and use of models including these parameters may help to optimize the scan speed of the pelvic region [12, 13].

The double tracking technique, which tracks a single test bolus at two different levels, may be able to accurately estimate the flow of the iliac arteries. A previous study performed run-off CTA using only 40 ml of contrast medium by optimizing the scan time to the arterial flow estimated by the double tracking technique [14]. The average transit time from the top of the abdominal aorta to the popliteal artery was longer than 10 s. However, the transit time from the top to the bottom of the aorta is much shorter. This may make it difficult to perform dynamic scans at two different levels of the aorta within a single test injection.

Previous studies attempted to decrease the amount of contrast medium during aortic CTA using low tube voltage [2, 15–20]. The amount of contrast medium injected when an 80 kVp protocol was used ranged from 33 to 70 ml with a flow rate ranging from 1.8 to 4.5 ml [2, 15–17]. The mean contrast medium injected in the present study was 33 ml, which was similar to the lowest amount reported in previous studies. The mean aortic enhancement in the present study was 449 HU, which was much higher than in previous studies due to the higher injection speed.

However, there is a discrepancy between the estimated and actual aortic enhancement and caution is required to maintain optimal enhancement even when the aortic enhancement is unexpectedly low.

Other approaches, such as dual-energy imaging, could decrease the amount of contrast medium required for aortic CTA [3, 21–23]. Dual-energy imaging has the advantage that the optimal energy level can be selected after CTA acquisition, especially when spectral detector CT is used [23]. Theoretically, an energy level close to the k-edge of iodine of 33.17 keV would result in better enhancement compared to other energy levels [16, 24]. A previous study indicated that up to 60% reduction in contrast medium volume could be achieved using dual-energy CT compared to single-energy 120 kVp scanning [22].

This study had a number of limitations. First, this was a single-center study and we used only one CT scanner for the DRTB technique. Further multicenter studies using CT scanners from different vendors are required to validate the results of this study. Second, we did not test the diagnostic performance required to detect endoleaks after endovascular aneurysm repair. Reducing the amount of contrast medium may lead to subtle endoleaks being overlooked. Follow-up study after endovascular aneurysm repair may resolve this issue. Third, we did not continuously change the amount of contrast medium for the main bolus based on peak enhancement of the test bolus. This was because peak enhancement at the aorta had to be kept slightly higher than the target of 380 HU to maintain enhancement of common femoral arteries, even when the enhancement was unexpectedly low. Finally, the calculation of the parameters might seem complicated and not durable for clinical practice. We use a commercially available spreadsheet software to calculate the parameters. The optimal values could be calculated within a minute just by typing the z-axis values and CT numbers.

In conclusion, an 80 kVp scan was feasible in lean patients to reduce the contrast medium volume to a mean of 33 ml, while maintaining enhancement and image quality comparable to the 100 kVp protocol for aortic CTA using the DRTB technique.

Compliance with ethical standards

Conflict of interest All authors declare no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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