Fat volume measurements as a predictor of image noise in coronary computed tomography angiography

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Introduction: **Image noise can negatively affect the overall quality of coronary computed tomography angiography (CCTA).**

Objectives: **The purpose of this study was to evaluate the relationship between image noise and fat volumes in the chest wall. We also aimed to compare these with other patient-specific predictors of image noise, such as body weight (BW) and body mass index (BMI).**

Methods: **We undertook a cross-sectional, single-center study. A tube voltage of 100 kV was used for patients with BW <85 kg and 120 kV for BW ≥85 kg. The image noise in the aortic root, single-slice fat volume (SFV) at the level of the left main coronary artery and the total fat volume of the chest (TFV) were analyzed.**

Results: **A total of 132 consecutive patients were enrolled (mean age þ standard deviation, 51 þ 11 years; 64% male). The mean image noise was 30.5 þ 11 Hounsfield units (HU). We found that patients with image noise >30 HU had significantly higher SFV (75 þ 33 vs. 51 þ 24, $p < 0.0001$) and TFV (2206 þ 927 vs. 1815 þ 737, $p < 0.01$) compared with patients having noise ≤30 HU, whereas BW and BMI showed no significant difference (78 þ 13 vs. 81 þ 14, $p < 0.34$) and (28.7 þ 4.7 vs. 26.8 þ 3.8, $p < 0.19$), respectively. Linear regression analysis showed that image noise has better correlation with SFV ($R = 0.399$; $p < 0.0001$); and TFV ($R = 0$, $p < 0.009$) than BMI ($R = 0.154$, $p < 0.039$) and BW ($R = –0.102$, $p = 0.12$).**

Conclusions: **Fat volume measurements of the chest wall can predict CCTA image noise better than other patient-specific predictors, such as BW and BMI.**

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1. Introduction

Coronary computed tomography angiography (CCTA) has become a well-established non-invasive test to detect coronary artery stenosis, with good diagnostic performance [1,2]. However, CCTA has limited use in morbidly obese patients, owing to higher image noise, which may compromise image interpretation and affect the diagnostic accuracy. Multiple patient-specific predictors of noise were identified such as body weight, body mass index (BMI) [3], transverse chest diameter [4], and thoracic solid tissue area (TSTA) [5]. An important technique to reduce image noise in overweight patients is increasing the tube current and/or tube voltage, which leads to increase in the total number and energy of the X-ray photons, respectively; this results in reduced noise with the trade-off of increased radiation [6–8]. Indeed, the selection of a suitable tube voltage (kV) should be made to achieve diagnostic image quality while maintaining as low a radiation dose as is reasonably possible. When appropriate, 120 kV is recommended if body weight is >85 kg or BMI is >30 kg/m^2 to eliminate noise and improve the signal and signal/noise ratio [9]. We hypothesized that chest wall fat measured by CCTA can predict image noise better than anthropometric measurements (weight and BMI). Our study sought to identify suitable patients for lower tube voltage (100 kV) during CCTA.

Abbreviations

TSTA	Thoracic solid tissue area
AUC	area under the curve
BMI	Body mass index
CCTA	Coronary computed tomography angiography
HU	Hounsfield units
SFV	Single slice fat volume
TFV	Total fat volume

2. Methods

Patients were enrolled in a cross-sectional single-center study at a tertiary cardiac center in Qassim province, Saudi Arabia, between March and July 2013. All patients were referred for CCTA, weight, height, BMI, waist and hip circumference, and waist/hip ratio measurements. The study was approved by the regional ethics committee, and all patients provided informed consent.

2.1. CCTA acquisition

Using a dual-source scanner (Siemens Flash® Definition CT scanner, Siemens Healthcare, Forchheim, Germany rotation time 280 ms), scout images were obtained from all patients, and calcium score scan (with 3-mm slice thickness) was performed. Electrocardiography (ECG) gating was used with either prospective or retrospective scans during deep inspiration. The ‘‘test bolus’’ technique was used with a 4-second delay time after the peak contrast enhancement of a region of interest in ascending aorta, using 15 mL contrast agent (370 mg iodine/mL), then 25 mL normal saline. The CCTA scan was carried out by injecting 80 mL contrast and 45 mL saline solution at a rate of 6 mL/s. Sublingual nitroglycerin was administered during the scan, along with beta-blockers, to maintain the heart rate at less than 65 beats/min.

For patients with body weight ≥85 kg a tube voltage of 120 kV was used, whereas 100 kV was used in patients with body weight <85 kg. The tube current was set to 320 mA for all prospective ECGs triggering the gating scan. We excluded patients who were imaged in the prospectively ECG-triggered high-pitch spiral acquisition mode.

2.2. Image reconstruction

A slice thickness of 3 mm for calcium scoring and 0.6 mm for CCTA, were reconstructed using filtered back projection algorithm with Medium smooth kernels (B26) for post-processing using a Multi-Modality Work Place Siemens Medical Solutions.

2.3. Fat volume measurement

Using calcium score data, a field of view of interest starting at the superior part of the left main coronary artery to the most inferior part of the heart was reconstructed to calculate the different fat volumes. Fat volumes were determined by manual tracing of the area of interest by setting the fat attenuation values within a range of –190 to –45 Hounsfield units (HU) [10,11]. (Fig. 1).

Single-slice fat volume (SFV) is defined as fat measured in a single axial image at the level of the left main coronary artery. The total fat volume (TFV) of the full field of view of interest was then calculated.

2.4. Thoracic solid tissue area

The TSTA was calculated by manually tracing the areas of interest at the level of the left main coronary artery, and determined as the thoracic cross section minus the lung/mediastinum area (Fig. 2).

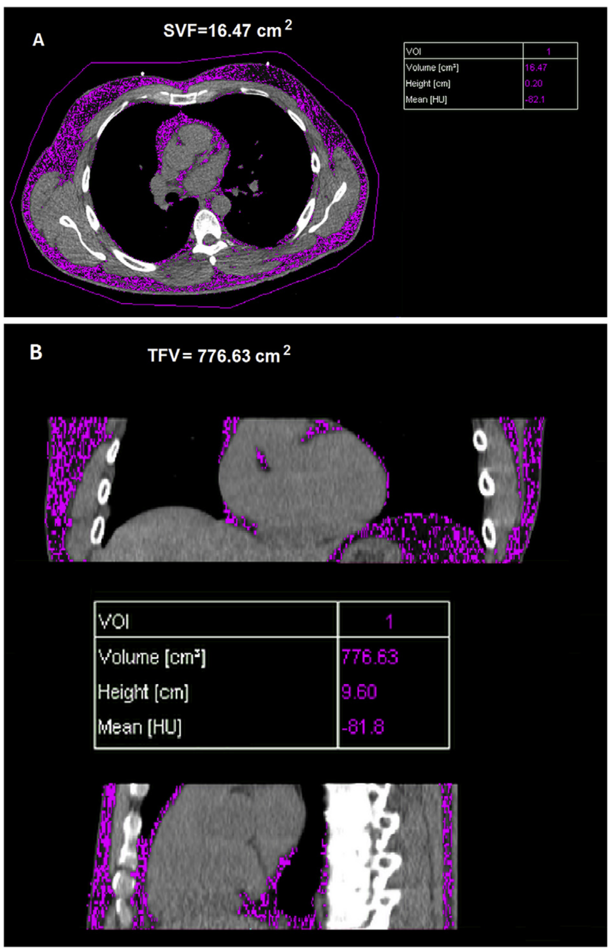

Figure 1. Measurement of fat volumes. (A) Single-slice fat volume (SFV) determined by tracing the external chest wall of a noncontract axial image at the level of left main coronary artery. (B) Sagittal and coronal noncontrast images show the total fat volume (TFV) that includes the total fat within the field of view between the superior part of the left main coronary artery to the most inferior part of the heart. HU = Hounsfield units.

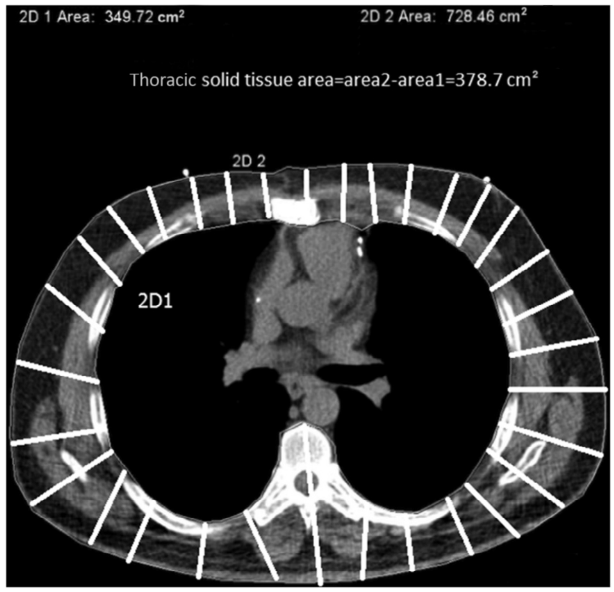

Figure 2. Axial image showed thoracic solid tissue area (determined by white lines): measured by tracing the external and internal chest wall area, then subtraction of the two areas.

2.5. Image quality assessment

Subjective and objective image quality were evaluated using a commercially available (Multi-Modality Work Place, MMWP®, Siemens Healthcare) workstation with a window width of 700 HU and 200 HU.

2.6. Objective image quality

Image noise was determined as the standard deviation (SD) of the CT attenuation of a 1-cm^2 circular region of interest placed in the aortic root at the level of the left main coronary artery [12]. The average SD of three sequential slices was taken. The image signal was defined as the average mean HU of the same three sequential fields of view used for noise calculation.

2.7. Subjective image quality

Image quality was scored visually by two observers using the 4-point scoring system, where 4 = excellent image quality; 3 = good quality; 2 = acceptable; 1 = poor nondiagnostic images [12]. The final score was averaged.

2.8. Statistical analysis

Continuous data are presented as mean ± SD, and categorical variables are expressed as number and percentage. We defined "high noise" as >30 HU as in previous reports [13–15], and *t* test analysis was used to compare numerical variables whereas chi-square analysis was used to compare categorical variables between groups with noise >30 HU versus ≤30 HU. Linear regression analysis was used to assess the correlation between the image noise with fat volumes and other parameters. Statistical analysis was performed using SPSS for Windows, Version 19.0 (SPSS Inc., Chicago, IL, USA). A p value <0.05 was considered statistically significant for all tests.

3. Results

3.1. Clinical characteristics

A total of 132 consecutive patients with a mean age of 51 ± 11 years were enrolled into the study; 85 (64%) were male. Other baseline characteristics are shown in Table 1. The mean total fat volume was 1990 ± 847 cm^3, the SFV was 146 ± 62 cm^3, the TSTA was 414 ± 110 cm^2, the noise was 30.5 ± 11 HU, and the mean heart rate during the scan was 66 ± 9 beats/min.

Table 1. Patient characteristics.

Variable	All patients (n = 132)
Age (y), mean ± SD	51 ± 11
Men, n (%)	85/132 (64%)
Diabetes mellitus, n (%)	49/132 (37%)
Hypertension, n (%)	64/132 (48%)
Dyslipidemia, n (%)	49/132 (37%)
Family history of coronary artery disease	8/132 (6%)
Current smoking, n (%)	25/132 (19%)
Body weight, mean ± SD	80 ± 13.6
Weight ≥85 kg, n (%)	54/132 (41%)
Heart rate (beats/min), mean ± SD	66 ± 9
Body mass index (kg/m^2), mean ± SD	30.2 ± 5.1
Hip (cm), mean ± SD	103 ± 25
Waist (cm), mean ± SD	99 ± 23
Prospective scan, n (%)	98/132 (74%)
Noise (HU), mean ± SD	30.5 ± 11
Radiation DLP (mGy) mean ± SD	437 ± 272
Radiation (mSv) mean ± SD	6.1 ± 3.8
Non-enhanced CCTA radiation (mSv), mean ± SD	0.72 ± 0.13

DLP = dose length product; HU = Hounsfield unit; mSv = millisievert; SD = standard deviation.

3.2. Fat volumes, chest area, and anthropometric variables correlation

Regression analysis showed a very good overall correlation between different CCTA measurements and anthropometric variables. TFV showed the highest correlation with BMI (R = 0.746, p = <0.0001). The correlation coefficients and corresponding p values for different variables are displayed in Table 2.

3.3. Image noise analysis

The patient cohort was divided into two groups according to image noise: patients with low image noise (≤30 HU; n = 73, 55.3%) and those with high noise (>30 HU; n = 59, 44.7%) (Table 3).

We found that patients with noise >30 HU had significantly higher SFV (75 ± 33 cm^3 vs. 51 ± 24 cm^3, $p < 0.0001$), TFV (2206 ± 927 cm^3 vs. 1815 ± 737 cm^3, $p = 0.01$), and TSTA (451 ± 115 cm^2 vs. 383 ± 96 cm^2, $p = 0.0005$) compared with patients having noise ≤30 HU, whereas weight and BMI showed no significant difference (78 ± 13 kg vs. 81 ± 14 kg, $p < 0.34$) and (28.7 ± 4.7 kg/m^2 vs. 26.8 ± 3.8 kg/m^2, $p < 0.19$), respectively.

Linear regression analysis including all patients showed correlations of image noise with fat volumes as follows: SFV, $R = 0.399$ ($R^2 = 0.160$; $p < 0.0001$); TFV, $R = 0.2$ ($R^2 = 0.040$; $p < 0.009$); TSTA, $R = 0.292$ ($R^2 = 0.0850$; $p < 0.0001$); BMI, $R = 0.154$ ($R^2 = 0.024$; $p < 0.039$); and body weight, $R = -0.102$ ($R^2 = 0.010$; $p = 0.12$) (Fig. 3).

Univariate logistic regression analysis showed that fat volumes (TFV and SFV), and TSTA are strong predictor for noise >30 HU. By contrast, BMI, body weight, and waist circumference did not predict noise level. In addition, multivariate regression showed that total fat volume TFV and TSTA can significantly predict image noise (Table 4). These results were consistent in the two different body weight groups (Table 5).

A receiver operating characteristic analysis in patients with body weight ≥85 kg (120 kV) showed

Table 2. CCTA and anthropometric measurements.

Variable	Weight	BMI	Waist	TFV	SFV	TSTA	
Body weight	1	0.742	0.597	0.569	0.428	0.581	Correlation
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	p value
BMI	0.742	1	0.46	0.747	0.678	0.695	Correlation
	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	p value
Waist	0.597	0.46	1	0.429	0.36	0.442	Correlation
	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	p value

Results showed very good correlation between different anthropometric variables and the CCTA measurements.
BMI = body mass index; SFV = single slice fat volume; TFV = total fat volume; TSTA = thoracic solid tissue area.

Table 3. Comparison between group A (with noise ≤30 HU) and B (with noise >30 HU) showed that group A has significantly smaller thoracic solid tissue area and fat volume measurements than group B.

Variables	Image noise ≤30	Image noise >30	*p*
Number of patients, *n* (%)	73 (55%)	59 (45%)	
Noise (HU), mean ± SD	23 ± 5	40 ± 8	<0.0001
Age (y), mean ± SD	51 ± 12	50 ± 8	0.8
Heart rate (beats/min), mean ± SD	63 ± 9	68 ± 8	0.003
Body weight, mean ± SD	81 ± 14	78 ± 13	0.34
Body mass index (kg/m^2), mean ± SD	26.8 ± 3.8	28.7 ± 4.7	0.19
Waist (cm), mean ± SD	96 ± 24	98 ± 21	0.56
Hip (cm), mean ± SD	100 ± 25	105 ± 23	0.23
Waist/hip ratio, mean ± SD	0.95 ± 0.06	0.94 ± 0.08	0.20
Signal (HU), mean ± SD	433 ± 116	468 ± 115	0.09
Signal/noise ratio, mean ± SD	19 ± 8	12 ± 3	0.0001
Quality score, mean ± SD	2.96 ± 0.6	2.78 ± 0.7	0.13
SFV (cm^3), mean ± SD	51 ± 24	75 ± 33	0.0001
TFV (cm^3), mean ± SD	1815 ± 737	2206 ± 927	0.01
TSTA (cm^2), mean ± SD	383 ± 96	451 ± 115	0.0005
100 kV, *n* (%)	35 (48%)	43 (73%)	0.013
Radiation DLP (mGy), mean ± SD	501 ± 301	359 ± 206	0.002
Retrospective scan, *n* (%)	19 (26%)	15 (25%)	0.12

DLP = dose length product; HU = Hounsfield unit; SFV = single slice fat volume; TFV = total fat volume; TSTA = thoracic solid tissue area.

that TSTA, TFV, and SFV were the best predictors of image noise >30 HU, with areas under the curve (AUCs) of 0.866 ($p < 0.0001$), 0.831 ($p < 0.0001$), and 0.840 ($p < 0.001$), respectively. These were followed by BMI (AUC = 0.736; $p = 0.006$) and body weight (AUC = 0.650; $p = 0.083$).

Similar results were found in patients with body weight <85 kg (100 kV). TFV and SFV significantly predicted the image quality with AUCs of 0.731 ($p < 0.0001$) and 0.730 ($p < 0.001$), respectively. These were followed by TSTA (AUC = 0.720; $p = 0.001$), BMI (AUC = 0.650; $p = 0.02$), and body weight (AUC = 0.560; $p = 0.3$; Fig. 4).

4. Discussion

In the present study, we compared the influence of chest wall fat volumes and anthropometric adiposity variables on image noise. We demonstrated a significant positive correlation between image noise and fat volumes. In addition, we found that fat measurement of the chest wall can predict image noise better than body weight and BMI.

The accuracy of CCTA is adversely affected by many factors that can degrade the image quality; these include patient-related factors such as heart rate variation that induces motion artifacts [16–18], blooming artifacts owing to excess coronary calcification [19], and increased image noise as a result of high BMI [20,21].

Adipose tissue is considered a principal component of the chest wall soft tissue. Increasing fat contributes to greater X-ray photon absorption during the scan, and this results in increased image noise as the number of photons reaching the detector will decrease [22].

Despite the technological developments and advances in computed tomography angiography, morbid obesity remains a limitation in achieving optimal image quality. In fact, there are different obesity-dedicated protocols to reduce image noise, such as using higher tube current during the scan, and higher tube potentials (120 kV or 140 kV); however, selection of eligible patients for higher tube voltages to maintain consistent image quality is a challenge as it may lead to inappropriate and excessive radiation exposure [23,24].

Automated tube voltage selection algorithms using the patient's attenuation profile obtained from the scout image are widely used for the setting of the tube current and voltage [25]. These algorithms are associated with a significant reduction in radiation exposure; however, this also increases the noise level when compared to BMI-based tube voltage selection [26,27].

In our study, we opted to analyze the fat volumes because we believe that adipose tissue has major contributions in obese patients compared with nonobese patients. Furthermore, in female patients, breast fat tissue may play a major role in image attenuation. Therefore, we believe that measuring fat volumes will reflect the degree of tissue attenuation and reflect the level of the

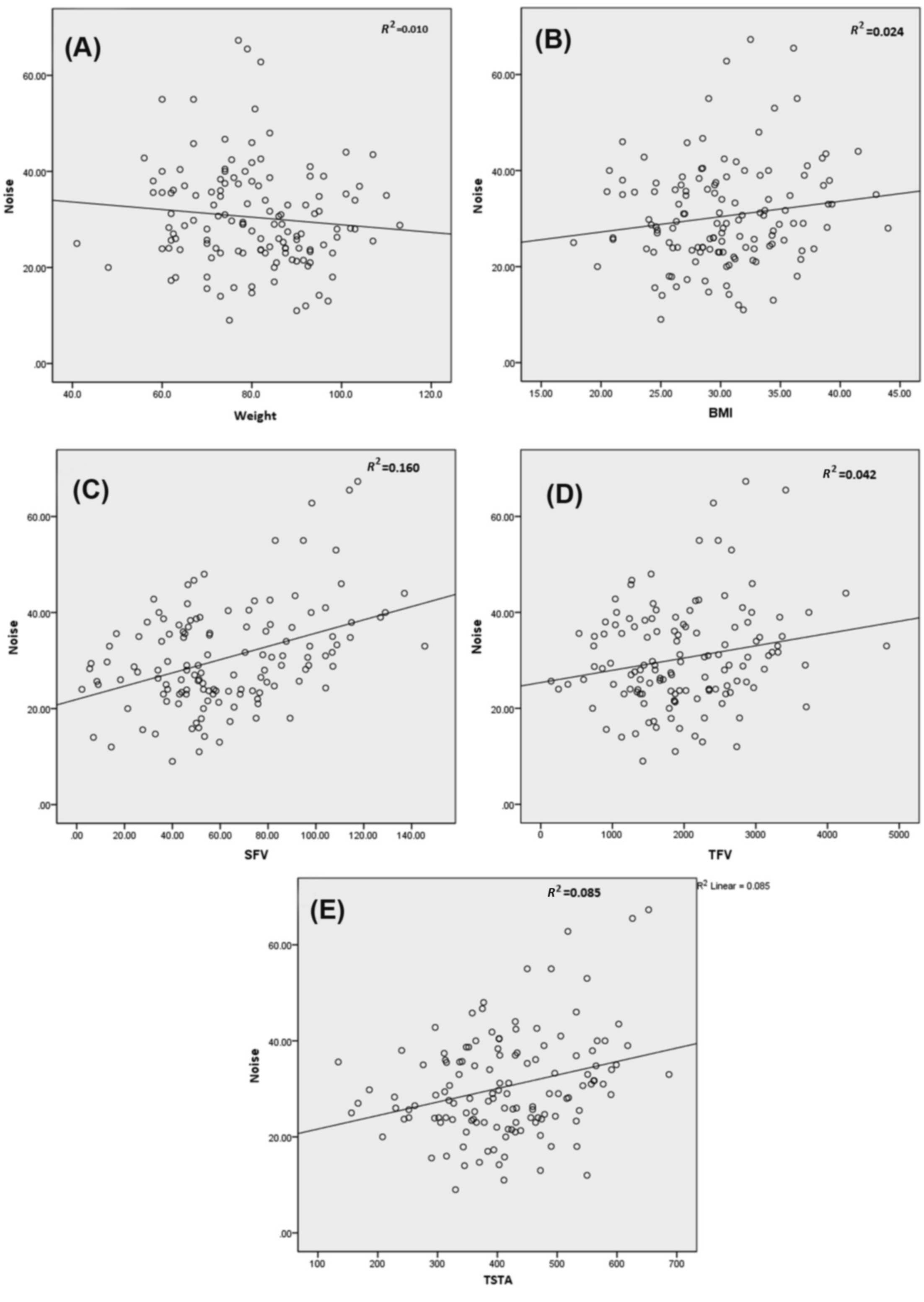

Figure 3. Scatter plots of the correlation. (A) Between noise and weight. (B) Between noise and body mass index (BMI). (C) Between noise and single-slice fat volume (SFV). (D) Between noise and total fat volume (TFV). (E) Between noise and thoracic solid tissue area (TSTA).

noise, allowing a suitable tube voltage to be chosen accordingly.

We observed that body weight, which is used for dose adaption, did not predict noise level. By contrast, BMI showed a higher correlation with CCTA fat measurements and, consequently a better prediction of noise compared with body weight.

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Table 4. Univariate and multivariate logistic regression for variables contribute to image noise including all patients in the study.

Variable	Univariate logistic regression		Multivariate logistic regression	
	HR (95% CI)	*p*	HR (95% CI)	*p*
BMI	1.048 (0.978–1.122)	0.18	1.008 (0.854–1.189)	0.9
Weight	0.988 (0.963–1.013)	0.34	0.933 (0.881–0.989)	0.019
Waist	1.044 (0.989–1.020)	0.56	1.011 (0.987–1.035)	0.39
TFV	1.001 (1.000–1.001)	0.01	1.012 (0.998–1.023)	0.026
SFV	1.029 (1.015–1.043)	<0.0001	1.049 (0.975–1.128)	0.2
TSTA	1.006 (1003–1.010)	0.001	1.009 (1.001–1.018)	0.028

BMI = body mass index; CI = confidence interval; HR = hazard ration = SFV = single slice fat volume; TFV = total fat volume; TSTA = thoracic solid tissue area.

Table 5. Univariate and multivariate logistic regression for variables contribute to image noise: (A) in patients with body weight ≥85 kg and (B) in patients with body weight <85 kg.

	Univariate logistic regression in patients with body weight ≥85		Multivariate logistic regression in patients with body weight ≥85	
(A)				
Variable	HR (95% CI)	*p*	HR (95% CI)	*p*
BMI	1.23 (1.043–1.458)	0.014	1.057 (0.765–1.462)	0.7
Weight	1.071 (0.98–1.16)	0.1	0.960 (0.823–1.120)	0.6
Waist	1.024 (0.977–1.073)	0.32	1.043 (0.964–1.128)	0.3
TFV	1.002 (1.001–1.003)	0.002	1.00 (0.998–1.002)	0.9
SFV	1.051 (1.020–1.083)	0.001	0.966 (0.873–1.069)	0.5
TSTA	1.018 (1007–1.029)	0.001	1.016 (1.000–1.003)	0.056
	Univariate logistic regression in patients with body weight <85		Multivariate logistic regression in patients with body weight <85	
(B)				
Variable	HR (95% CI)	*p*	HR (95% CI)	*p*
BMI	1.012 (1.002–1.255)	0.046	1.023 (0.822–1.273)	0.8
Weight	1.026 (0.974–1.081)	0.32	1.011 (0.930–1.10)	0.78
Waist	1.009 (0.990–1.028)	0.36	0.999 (0.972–1.026)	0.9
TFV	1.001 (1.000–1.001)	0.020	1.021 (0.933–1.102)	0.03
SFV	1.034 (1.014–1.054)	0.001	1.081 (0.991–1.178)	0.078
TSTA	1.007 (1002–1.013)	0.013	1.002 (0.996–1.007)	0.5

BMI = body mass index; CI, confidence interval; SFV = single-slice fat volume; TFV = total fat volume; TSTA = thoracic solid tissue area.

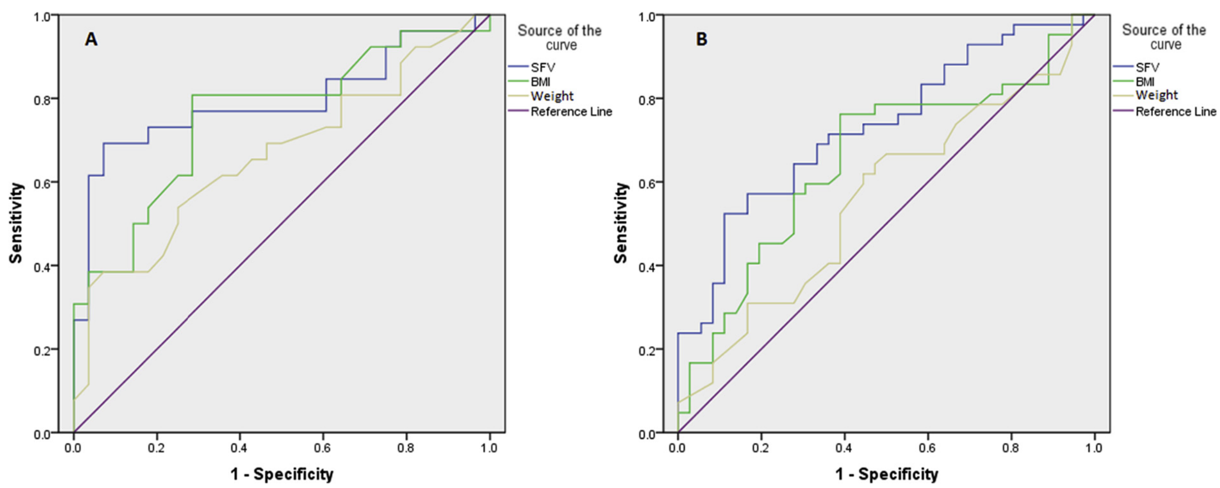

Figure 4. Receiver operating characteristic analysis of the anthropometric variables. Thoracic solid tissue area (TSTA) and single-slice fat volume (SFV) measurement in patients. (A) For patients with body weight ≥85 kg. (B) For patients with body weight <85 kg. Results show that area under the curve was significantly larger with fat volume than with body mass index (BMI) and body weight.

Few data have been published to study the relationship between fat and image quality. A very strong correlation ($R = 0.82$) between TSTA and image noise was reported by Paul et al. [28], who—in contrast to our study—conducted a retrospective analysis in patients with a BMI below 35 kg/m^2 and the noise estimated in noncontrast scan.

Furthermore, our results were comparable to those of Ghoshhajra et al. [29], who showed a strong correlation between BMI and the area of thoracic cross section ($R = 0.84$) as compared with our data ($R = 0.695$). Moreover, Schuhbaeck et al. [5] investigated the role of TSTA in predicting image quality; they reported similar findings to our study and concluded that TSTA is a strong predictor of noise.

Fat volumes can be measured easily and reproducibly [30] using calcium score imaging data before setting the tube potentials prior to CCTA. We recommend measuring fat volumes during the scan and using these data for dose adaption.

Further studies using test bolus are warranted to compare the effect of fat volumes with Scout View X-ray Attenuation on image quality to identify the best predictor of noise [13].

Our study has several limitations. The tube voltage was set to 100 kV when body weight was <85 kg and 120 when body weight was ≥85 kg, regardless of the patient's BMI. Patients with high probability of coronary artery disease or previous revascularization were excluded. Furthermore, noise was measured in a single slice at the level of left main, although averaged measurement at different levels may better reflect the image quality. Finally, all patients required non-contrast coronary scan to measure fat, which may slightly increase the radiation dose.

5. Conclusion

Fat volume measurements of the chest wall may add valuable information about the degree of tissue attenuation and may predict the level of image noise in CCTA more accurately than other patient-specific predictors of noise. This may help to identify patients requiring a lower tube voltage of 100 kV.

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