

Subcutaneous Tissue Thickness is an Independent Predictor of Image Noise in Cardiac CT

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Abstract

Background: Few data on the definition of simple robust parameters to predict image noise in cardiac computed tomography (CT) exist.

Objectives: To evaluate the value of a simple measure of subcutaneous tissue as a predictor of image noise in cardiac CT.

Methods: 86 patients underwent prospective ECG-gated coronary computed tomographic angiography (CTA) and coronary calcium scoring (CAC) with 120 kV and 150 mA. The image quality was objectively measured by the image noise in the aorta in the cardiac CTA, and low noise was defined as noise < 30HU. The chest anteroposterior diameter and lateral width, the image noise in the aorta and the skin-sternum (SS) thickness were measured as predictors of cardiac CTA noise. The association of the predictors and image noise was performed by using Pearson correlation.

Results: The mean radiation dose was 3.5 ± 1.5 mSv. The mean image noise in CT was 36.3 ± 8.5 HU, and the mean image noise in non-contrast scan was 17.7 ± 4.4 HU. All predictors were independently associated with cardiac CTA noise. The best predictors were SS thickness, with a correlation of 0.70 ($p < 0.001$), and noise in the non-contrast images, with a correlation of 0.73 ($p < 0.001$). When evaluating the ability to predict low image noise, the areas under the ROC curve for the non-contrast noise and for the SS thickness were 0.837 and 0.864, respectively.

Conclusion: Both SS thickness and CAC noise are simple accurate predictors of cardiac CTA image noise. Those parameters can be incorporated in standard CT protocols to adequately adjust radiation exposure. (Arq Bras Cardiol. 2014; 102(1):86-92)

Keywords: Sternum / radiation effects; Radiation injuries; Computed tomography; Artifacts.

Introduction

Cardiac computed tomographic angiography (CTA) is a useful and accurate tool to evaluate the coronary arteries and cardiac structure¹. Although cardiac CTA is safe, the use of radiation poses a small risk², which has raised concerns, because of the increasing number of medical tests using radiation³. In particular, younger patients and women are at a particularly higher risk of long-term complications following radiation exposure⁴.

The reduction in radiation exposure has been the aim of many recent advances in cardiac CTA, including the use of tube current modulation⁵, prospectively ECG-triggered axial scan⁶ and newer acquisition modes⁷, as well as the

adequate adjustment of the kV and mA used during image acquisition^{5,8,9}. Additionally, studies have shown that the combination of several techniques¹⁰ and exposure estimation based on complex calculations are also helpful in optimizing radiation exposure¹¹. More recently, the use of iterative reconstruction techniques have also been proposed as a potential dose sparing technique¹²⁻¹⁵.

Although effective, the inadequate or excessive use of those techniques may affect image quality and result in limited or inadequate scans. The main adverse effect of lowering the radiation dose is the image noise increase caused by a reduction in the number of photons that reach the detectors³.

The main cause of increased noise in cardiac CTA is the interposed extracardiac structures. Therefore, many protocols rely on measures associated with the patient's body constitution, e. g. body mass index (BMI)¹⁶, patient's chest circumference¹⁷ and diameter¹⁸ to adjust the radiation parameters. Guidelines currently recommend the use of chest anteroposterior (AP) diameter or chest lateral width to estimate the radiation dose¹⁸, although this strategy has not yet been validated or compared to other techniques.

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Thus, in this study we aimed at objectively evaluating the association of BMI, chest AP diameter, and chest lateral width with the amount of noise in cardiac CTA images. Additionally, we hypothesized that the subcutaneous tissue measurement at the level of the sternum and the noise in non-contrast images would better correlate with image noise.

Methods

We enrolled 86 consecutive patients who underwent prospective ECG-gated cardiac CTA and calcium scoring with the same tube potential and tube current following the same injection protocol. All coronary cardiac CTAs were performed to evaluate known or suspected coronary artery disease. The study was approved by the local institutional ethics committee, and all participants signed the written informed consent. Data on patient characteristics and clinical information were collected prospectively as part of an institutional database.

All patients with a heart rate above 60 bpm received oral beta-blockers prior to image acquisition. Cardiac CTA scans were performed in a 64 row multi-slice scanner (Brilliance 64, Philips Healthcare, Best, Netherlands). The scout images were acquired with 120 kV and 30 mA. After the scout images, all patients also underwent a prospectively ECG-gated calcium scoring with a tube potential of 120 kV and a tube current of 55 mA. The contrast-enhanced cardiac CTA was performed with a collimation of 64 x 0.625 mm, gantry rotation time of 400 milliseconds with tube current of 150 mA and tube potential of 120 kV. The slice thickness was selected as 0.8 mm, increment of 0.4 mm, using 100 ml of iodine contrast (Ultravist 370, Bayer, Germany) injected with a dual head injector (Medrad Inc., U.S.A.) at a rate of 6 ml/seconds followed by 60 ml of saline at the same rate, using a 18 gauge in the antecubital vein. Automated bolus tracking was used by placing a circular region of interest in the descending aorta and acquisition was triggered when the average attenuation value in the region of interest reached 150 Hounsfield Unit (HU). The 75% R-R interval image was used for image reconstruction and coronary analysis. Images were reconstructed using standard filtered back projection and a standard kernel.

Factors related to patient characteristics and injection protocols that affect the aorta contrast were considered. We enrolled patients with similar heart rate, varying from 50-60 bpm, with no history of heart failure and we used the same injection protocol for the whole sample, with a total of 100 ml iodine contrast at 6 ml/s, followed by 60 ml of saline solution at 6 ml/s, using an 18 gauge in the antecubital vein. The image noise in computed tomography (CT) was defined as the standard deviation measured with a region of interest of 1 cm² in the ascending aorta (Figure 1A). The chest AP diameter was measured on the chest digital axial cross-section image with a line passing through the middle of the heart (Figure 1B), the skin-sternum (SS) thickness was measured from the skin to the sternum in the middle intermammary level (Figure 1C), and the chest lateral width was measured on the topogram from skin to

skin at the level of the left hemidiaphragm (Figure 1D). The image noise calculation in the aorta was also measured as standard deviation units, with a region of interest of 1 cm² in the prospective calcium score using a fixed tube potential of 120 kV and a tube current of 55 mA (Figure 1E). The BMI was calculated as the weight in kilograms divided by the squared height in meters.

Statistical Analysis

All continuous variables have been inspected for normality and presented as mean \pm standard deviations as no significant departures from normality were detected. Categorical variables were presented in absolute and relative (%) frequencies. The relationship between image noise in the cardiac CT and BMI, chest AP diameter, SS thickness, chest lateral width and aorta noise in calcium score imaging was evaluated using Pearson correlation and linear regression. For comparing Pearson correlations, the Fisher's z approximation was used. Multivariate linear regression models were built to identify the best combination of predictors to estimate cardiac CTA noise. To define the best prediction model, the lowest adjusted R² value was used. Additionally, the image noise was dichotomized as 'low noise', if SD < 30 HU, and 'high noise', if SD > 30, as in previous reports^{19,20}. Receiver-operating characteristic (ROC) curve analysis to predict the 'low noise' images was performed for each of the predictors. A p-value of less than 0.05 was considered significant. The Bonferroni adjustment was applied to adjust for multiple comparisons. The Stata program, version 12, (StataCorp) was used for all statistical analyses.

Results

Table 1 shows the characteristics of the patient population. The mean total radiation dose, including CAC and cardiac CTA was 3.5 \pm 1.5 mSv; the mean image noise in the CT was 36.3 \pm 8.5 HU, and the mean image noise in the non-contrast scan was 17.7 \pm 4.4 HU.

All individual parameters were significantly associated with the noise in the cardiac CTA. Pearson correlation values are shown in Table 2, and the correlation matrix is shown in Figure 2. In a pairwise comparison, the CAC noise, BMI and SS thickness have a more significant correlation with cardiac CTA noise than any of the chest diameters ($p < 0.001$ for all comparisons). The correlation of CAC noise with outcome showed a trend towards being more significant than BMI ($p = 0.05$), whereas the CAC noise and SS thickness ($p = 0.16$), as well as the SS thickness and BMI correlations ($p = 0.13$) were not significantly different. In the multivariate analysis, the best prediction model included the association of CAC noise and SS thickness, with an adjusted R² of 0.61 ($p < 0.0001$).

Similarly, the best independent predictor of 'low noise' was SS thickness with an area under the ROC curve (AUC) of 0.86 (95% confidence interval (CI): 0.79 – 0.94) (Figure 3), followed by CAC noise (AUC of 0.84; 95% CI: 0.75 – 0.93), BMI (AUC of 0.80; 95% CI: 0.69 – 0.91), chest AP diameter (AUC of 0.62, 95% CI: 0.49 – 0.75), and chest lateral width (AUC of 0.59; 95% CI: 0.47 – 0.73) (Figure 2).

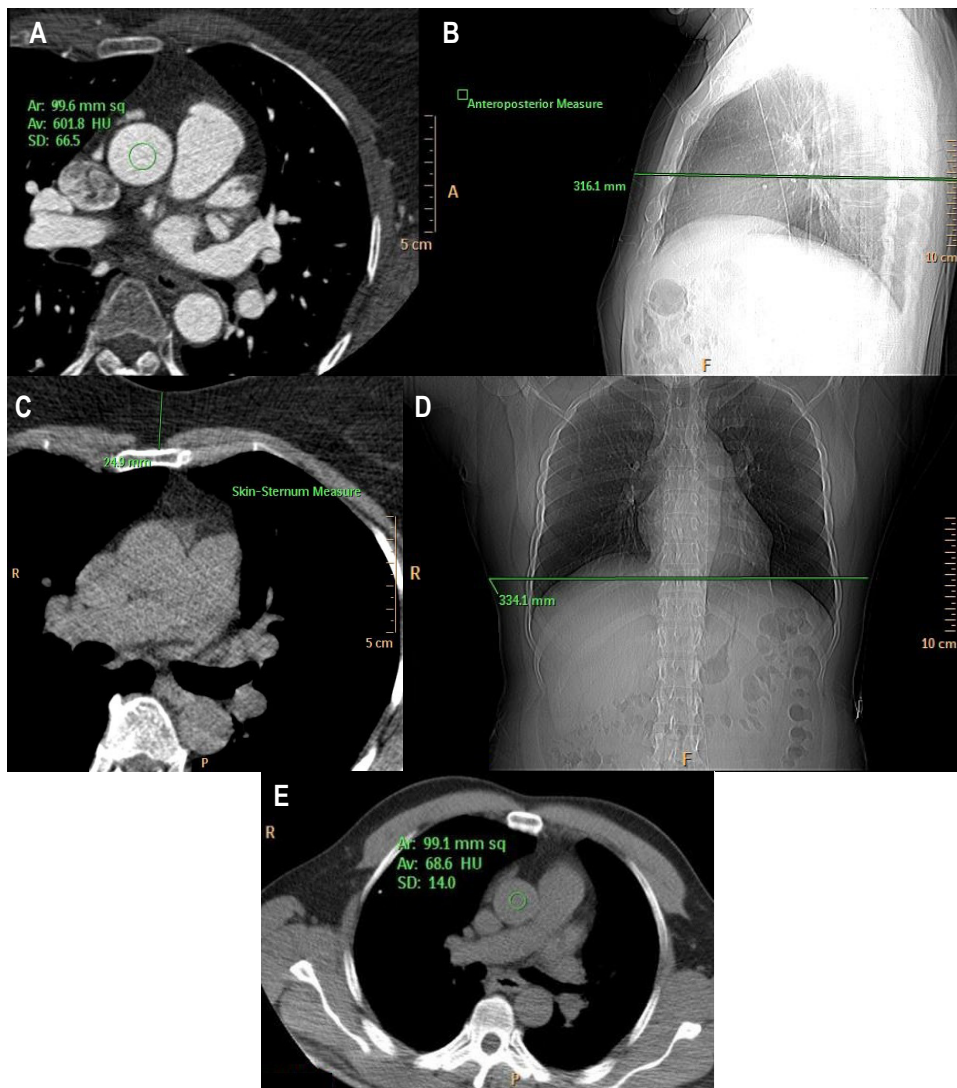


Figure 1 - A) Aorta noise measurement with an 1-cm² region of interest in the ascending aorta. B) Chest anteroposterior diameter measurement. C) Skin-sternum thickness measurement. D) Chest lateral width measurement. E) Calcium score noise measurement.

Table 1 - Baseline characteristics of the population

	Male	Female	Total
N	41	45	
Age (years)	59.6 ± 7.1	60.7 ± 7.8	59.8 ± 7.5
BMI (kg/m ²)	25.6 ± 3.5	28.3 ± 4.1	26.9 ± 3.9
AP diameter (mm)	290 ± 30	289 ± 22	289 ± 27
LW (mm)	376 ± 34	370 ± 38	373 ± 36
CAC noise (HU)	16.2 ± 3.4	19.4 ± 4.8	17.6 ± 4.4
SS thickness (mm)	10.8 ± 4.1	20.1 ± 6.9	15.2 ± 7.3
CCTA noise (HU)	32.0 ± 5.3	41.1 ± 8.9	36.2 ± 8.4
Low noise (< 30 HU) (%)	3 (7%)	20 (44%)	26 (27%)

BMI: body mass index; AP: anteroposterior; LW: lateral width; CAC: calcium score; SS: skin-sternum; CCTA: cardiac computed tomographic angiography; HU: Hounsfield units.

Table 2 - Pearson correlation of the predictors vs image noise in cardiac computed tomographic angiography

Parameter	Pearson correlation	p-value
BMI	0.61	< 0.0001
AP diameter	0.23	0.46
LW	0.31	0.042
CAC noise	0.73	< 0.0001
SS thickness	0.70	< 0.0001

BMI: body mass index; AP: anteroposterior; LW: lateral width; CAC: calcium score; SS: skin-sternum.

Discussion

The present study assessed two new parameters (CAC noise estimation and SS thickness) to better predict the image noise in contrast-enhanced cardiac CTA *versus* the currently recommended parameters of chest diameter, although the results of the new measures as compared to BMI did not reach statistical significance. Our study demonstrated that both parameters are better predictors of image noise than the currently recommended chest diameter techniques. Additionally, both parameters improved the image noise prediction when associated with the currently best predictor (BMI). Finally, they also had the best performance to discriminate cardiac CTA scans with a 'low noise', defined as a SD <30 HU.

Although the best fitting model included both parameters, the increase in R² by combining both parameters was small, and we believe a more parsimonious model including either one of the two variables or BMI in a univariate model would be better suited to routine radiation exposure adjustments.

The identification of a single parameter as a better predictor of image noise has been the focus of recent publications^{17,20,21}. Those studies have focused on measuring the subcutaneous tissue as a predictor of image noise. Gao et al²⁰ have used a measurement of the X-ray attenuation of the thorax in the scout images of patients undergoing cardiac CTA. Their data suggest that this measurement is a better predictor of cardiac CTA image noise than BMI or weight. In the study by Schuhbaeck et al²¹ a more advanced measurement of the entire chest wall at the level of the aortic root was used, and the authors concluded that such measure is significantly better than other predictors, including BMI²¹. Finally, Ghoshhajra et al¹⁷ have measured the chest area for the same purposes¹⁷. The main limitation of those studies was the inclusion of different acquisition protocols with different radiation exposures. Since those parameters were defined based on patients' characteristics, both studies might have overestimated the association of the measurements with the final cardiac CTA noise.

Our study restricted the analysis to similar patients submitted to the same acquisition protocol (with the same kV, mA, contrast rate and acquisition mode). In our sample, patients with heart failure were excluded and the image acquisition was performed with similar heart rates (range,

50-60 bpm), adjusting the factors that could affect aorta contrast enhancement. The main reason for this choice is that kV, mA and acquisition mode are usually chosen based on the patient's weight, BMI and heart rate. With this restriction we avoid the spurious association between predictors and outcome, due to the indication bias of selecting the most appropriate parameters prior to the image acquisition based on patients' characteristics.

Previous studies have demonstrated that image-based parameters are more precise than other patients' characteristics, such as BMI. Our study also showed that SS thicknesses and the direct measurement of noise in non-contrast images corroborate those prior data. These simple measurements take less than one minute and can be performed as part of a usual cardiac CTA acquisition flow without additional radiation or cost.

As demonstrated by Ghoshhajra et al¹⁷, those measurements lead to a better use of radiation. Not only is radiation exposure reduced in most cases, but precise measurements can lead to the use of higher doses in appropriate cases, which should be the goal of cardiac imaging²².

Among the various radiation-reducing techniques, the recently introduced use of automated attenuation-based tube potential selection was able to reduce radiation exposure by about 25%²³. This automated method is used in image attenuation as part of an automated algorithm to define radiation exposure. The SS thickness can be seen as a simplified version of the concept of chest attenuation as a predictor of image noise. Nevertheless, additional data is needed to define the appropriate adjustments in mA and kV of the current measurements.

Our study must, however, be read in the context of its design. First, to allow precise correlation of patients' measurements and noise estimation, only a fixed protocol was used. Therefore, the definition of the adequate mA and kV adjustments of these measures cannot be evaluated in the current data. Second, although simple, these measurements add an extra step to image acquisition. Third, this can only be used in patients who undergo a non-contrast scan prior to the cardiac CT. In cases where the non-contrast scan is not performed, the non-contrast noise cannot be calculated, but the SS thickness can still be measured in the contrast timing images.

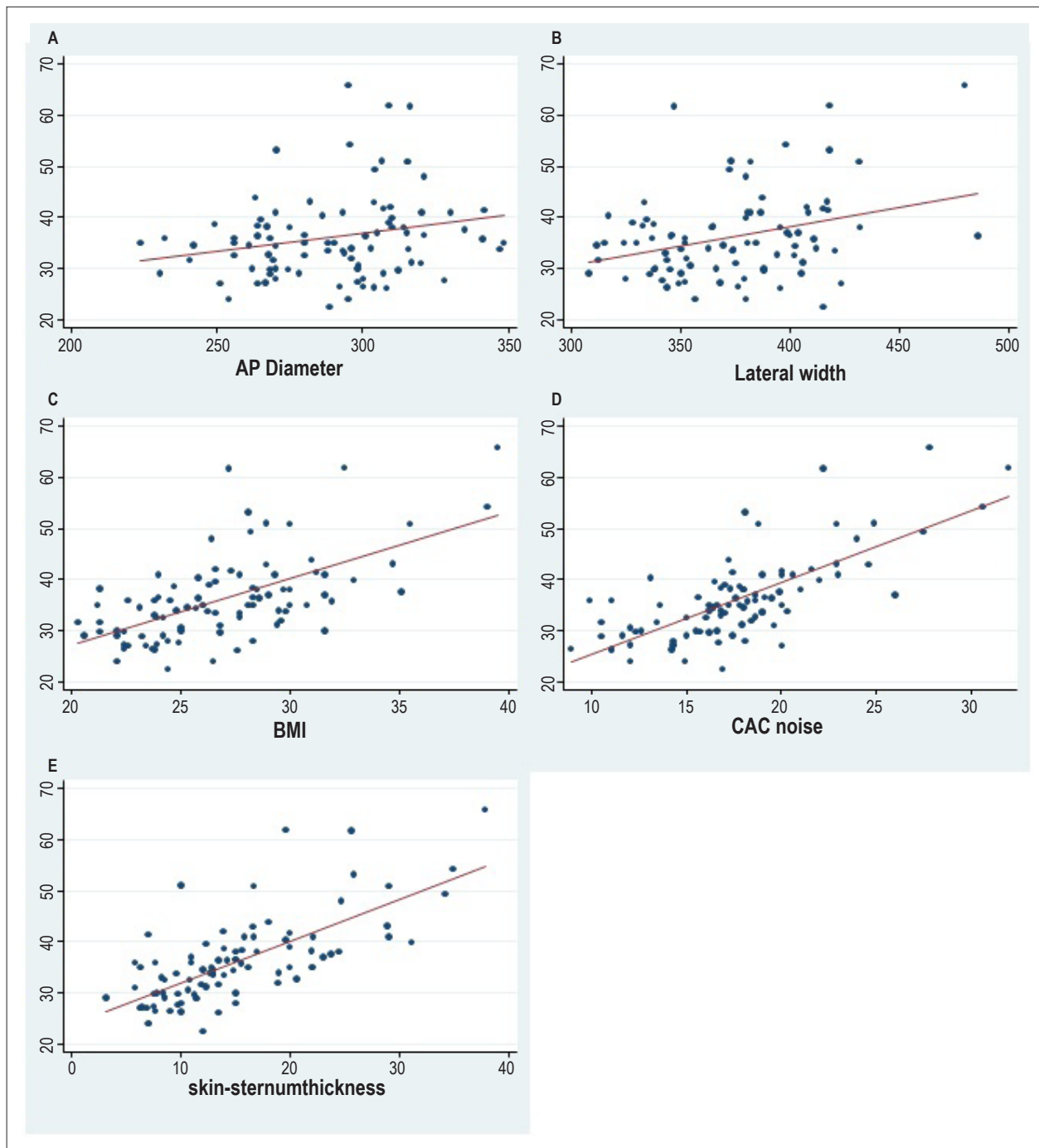


Figure 2 - Scatter plots of each of the predictors vs. cardiac CTA noise, including the regression lines. A) AP diameter; B) Lateral width; C) BMI; D) CAC noise; and E) Skin-sternum thickness.

Conclusion

Both SS thickness and CAC noise are simple accurate predictors of cardiac CTA image noise. Those parameters can be incorporated in standard CT protocols to adequately adjust radiation exposure.

Author contributions

Conception and design of the research: Staniak HL, Sharovsky R, Bensenor I, Lotufo PA, Bittencourt MS; Acquisition of data: Staniak HL, Sharovsky R, Bittencourt MS; Analysis and interpretation of the data: Staniak HL, Sharovsky R, Pereira AC,

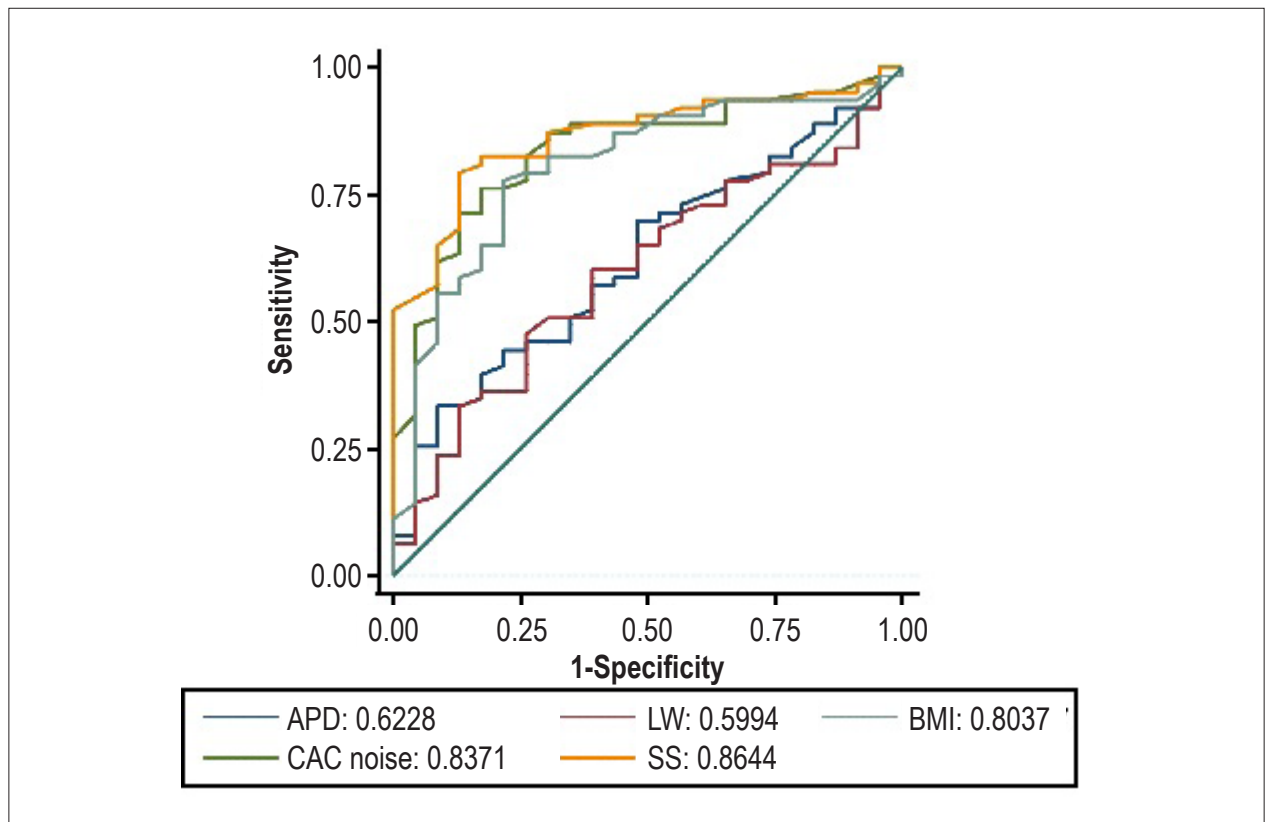


Figure 3 - Receiver operating characteristic curves for each of the predictors as an estimator of 'low image noise' in cardiac CTA. The area under the ROC curve value is presented in the legend for each parameter. APD: anteroposterior diameter; LW: lateral width; SS: skin-sternum thickness; BMI: body mass index; CAC: calcium score.

Bittencourt MS; Statistical analysis: Staniak HL, Sharovsky R, Pereira AC, Bensenor I, Lotufo PA, Bittencourt MS; Writing of the manuscript: Staniak HL, Bittencourt MS; Critical revision of the manuscript for intellectual content: Staniak HL, Sharovsky R, Pereira AC, Castro CC, Bensenor I, Lotufo PA, Bittencourt MS.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any post-graduation program.

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