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Image quality, contrast enhancement and radiation dose of ECG-triggered versus non-ECG-triggered imaging of the aorta on a single source 256-slice CT scanner

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ABSTRACT

Introduction: Computed tomography angiography of the aorta (CTAA) is the modality of choice for investigating aortic disease. Our aim was to evaluate image quality, contrast enhancement and radiation dose of electrocardiograph (ECG)-triggered and non-ECG-triggered CTAA on a 256-slice single source CT scanner. Knowledge of these will allow requesting clinician and radiologist to balance radiation risk and image quality.

Methods: We retrospectively assessed data from 126 patients who had undergone CTAA on a single-source CT scanner using ECG-triggered (group 1, n = 77) or non-ECG-triggered (group 2, n =49) protocols. Radiation doses were compared. Qualitative (4-point scale) and quantitative image quality assessments were performed.

Results: The mean volume CT dose index, dose length product and effective dose in group 1 were 12.4 ± 1.9 mGy, 765.8 ± 112.4 mGy x cm and 13.0 ± 1.9 mSv, respectively. These were significantly higher compared with group 2 (9.1 ± 2.6 mGy, 624.1 ± 174.8 mGy x cm and 10.6 ± 3.0 mSv, respectively) ($p < 0.001$). Qualitative assessment showed image quality at the aortic root-proximal ascending aorta was significantly higher in group 1 (median = 3) than in group 2 (median = 2, $p < 0.001$). Quantitative assessment showed significantly better mean arterial attenuation, signal-to-noise ratio and contrast-to-noise ratio in ECG-triggered CTAA compared with non-ECG-triggered CTAA.

Conclusion: ECG-triggered CTAA in a single-source scanner has superior image quality and vessel attenuation of aortic root/ascending aorta but a higher radiation dose of approximately 23%. Its use should be considered specifically when assessing aortic root/ascending aorta pathology.

Keywords: aortic diseases, computed tomography angiography, radiation dosage, retrospective studies, signal-to-noise ratio

INTRODUCTION

In the assessment of aortic disease, advances in multislice computed tomography (CT) technology have made CT scanning widely available and affordable. CT is the imaging modality of choice of the aorta as it is non-invasive, has high spatial resolution and shorter examination times.(1,2) CT angiography of the aorta (CTAA) is commonly used to evaluate suspected acute aortic syndromes, for follow up of atherosclerotic disease and its complications and in post-operative patients.(3,4)

For the requesting clinician, understanding the different imaging protocols for the aorta, in particular that of ECG-triggered and non-ECG-triggered CTAA, and their implications is important. ECG-triggered CTAA uses prospective ECG gating (also known as the “step and shoot” technique) where the tube current is triggered for only a short segment of the R-R interval at a pre-set time after the R wave. The table is stationary during image acquisition and then moves to the next location for imaging of the next segment of the aorta that is initiated by the subsequent cardiac cycle with little overlap between the scans.(5,6)

Non ECG-gated CTAA is beneficial due to its speed and considerable reduction in dose and contrast media volume use.(7) However, there are several disadvantages, most notably that of cardiac pulsation artefacts which affect the aortic root and periaortic structures. This can simulate a dissection flap resulting in false positive diagnoses or limit evaluation of the proximal coronary arteries.(8,9) This has an important impact on management, such as in surgical planning for Stanford type A aortic dissection with coronary artery involvement.(10)

Prospective ECG-triggered CTAAs require longer acquisition times compared with non-ECG-triggered CTAAs. However, they have been shown to be useful in the acute setting in assessing the thoracic aorta and coronary arteries,(11) with higher fidelity in the assessment of the aortic root and extension in relation to the coronary ostia.(12,13)

ECG-triggered CTAAs on a dual source CT scanner result in higher quality images of the aortic root and ascending aorta with good contrast enhancement and decreased estimated radiation dose compared with non ECG-triggered CTAA.(14) To the best of our knowledge, in the current medical literature, there are no published papers concerning this topic using a single source CT scanner. Given that single source scanners are still widely used, we sought to compare the image quality and radiation dose between ECG-triggered and non-ECG-triggered protocols for CTAA on a 256-slice single source scanner.

Awareness of these differences will allow the clinician and radiologist to balance potentially conflicting goals of optimising vessel attenuation, reducing motion artefacts and minimising radiation burden.

METHODS

This study was approved by the Domain Specific Review Board under the exempt category.

In a retrospective search of our institution's Radiology Information System (RIS), we identified 162 CTAA studies in a 6-month period. From these, 34 studies were excluded due to missing CT scanner dose reports that could not be retrieved. Another 2 studies were excluded as patient weight was not available on the hospital patient records system.

Of the 126 studies analysed, 77 were scanned using an ECG-triggered protocol (group 1) and 49 using the non-ECG-triggered protocol (group 2). The protocol for each patient was determined during a vetting process by a radiology resident, based on the history provided by the requesting clinician. Patient characteristics such as age, gender and weight, as well as indication for the study were recorded for all patients.

The patients included in this study were scanned on a 256-slice multidetector CT scanner (Brilliance iCT, Philips Healthcare, Cleveland, Ohio, USA). This has a detector collimation of 128 × 0.625 mm with double z-sampling, a spatial resolution of 0.625 mm, 0.27 sec gantry rotation time and temporal resolution of 135 msec.

All examinations were obtained in a craniocaudal direction from the thoracic inlet to the ischial tuberosities. Patients had an 18G cannula placed either in the antecubital fossa or dorsum of the hand. No medications were administered for heart rate or rhythm control prior to the scans.

All examinations included an arterial phase. Some studies included a non-contrast and delayed phase, usually in patients with prior stenting or previous surgery. Only data from the arterial phase was used in this study.

The scanning delay was determined using an automatic bolus tracking technique. An unenhanced scan was obtained at the level of the aortic root. A 10 mm diameter circular region of interest (ROI) was placed inside the lumen of the descending thoracic aorta on this scan. Based on the weight of the patient and total scanning time, 50-80 mL of non-ionic contrast medium (Omnipaque 350, GE Healthcare, USA) was injected at a flow rate of 4 mLsec, followed by a 50-60 mL saline bolus at the same injection rate using a dual-head injector (Stellant D; Medrad, Warrendale, PA, USA). The arterial phase scan was initiated once the attenuation value in the ROI exceeded 150 Hounsfield units (HU).

For ECG-triggered examinations, data was acquired using a prospectively ECG-triggered step and shoot mode in mid-diastole (78%) of the RR interval, for the entire aorta. This generated a single data set, which is important for pre-operative planning if required. During the remainder of the RR interval, no tube current was applied. The following RR interval was used to move the table in the z-direction to prepare for the next scan. The field of view (FOV) was adjusted to include the lateral skin borders tightly as a small FOV leads to increased z-coverage.(15)

For non-ECG-triggered studies, data was acquired in spiral mode with a pitch value of 0.8. Peak kilovoltage of 100 kVp or 120 kVp was used with automatic exposure control (DoseRight, Philips Healthcare, Cleveland, Ohio, USA) according to patient size.

For both ECG-triggered and non-ECG-triggered studies, images were reconstructed with a slice thickness of 0.8 mm with a 50% overlap in slice increment with 4th generation advanced iterative reconstruction (iDOSE^4; level 4). A medium soft-tissue kernel was used and image matrix size was set at 512 x 512. All images were transferred to a thin-client server (Intellispace Portal 5.0, Philips Healthcare, Cleveland, Ohio, USA) for analysis.

Volume CT dose index (CTDI$_{vol}$) values were indicated in the dose report of the CT system provided for each CT study. Individual radiation dose was estimated using the dose length product (DLP) given by the CT system.

To determine the effective dose (ED), we applied a normalised coefficient (E$_{DLP}$) to the DLP using the following formula: ED (mSv) = DLP * E$_{DLP}$. According to the "European guidelines on quality criteria for computer tomography", we used an E$_{DLP}$ of 0.017 (mean of region-specific conversion coefficients of the chest, abdomen and pelvis).(16) Although this coefficient has been revised, with a coefficient of 0.014 for chest and 0.015 for abdomen,(17) we preferred to use the previous value of 0.017 in order to simplify the calculation of the effective dose obtained from a thoraco-abdominal CTAA.

Effective dose does not represent a patient specific dose but provides a means for comparing the dose resulting from scanning protocols for groups 1 and 2.(18)

Image quality assessment was based on review of axial images by two experienced cardiac radiologists (reviewer 1, 13 years' cardiac radiology experience; reviewer 2, 5 years' cardiac radiology experience), who were blinded to the gating status of the study. The aorta was assessed in 3 different segments – [1] at the aortic root and ascending aorta, [2] the descending thoracic aorta and [3] the abdominal aorta.

The reviewers gave each segment an overall grade according to the following scale – 1, non-diagnostic (impaired image quality that precludes appropriate evaluation due to severe motion artefacts, extensive atherosclerotic calcification, severe image noise or insufficient contrast); 2, adequate (reduced image quality because of artefacts due to motion, image noise or low contrast attenuation); 3, good (presence of artefacts caused by motion, image noise, atherosclerotic calcifications or low contrast but fully preserved ability to assess the aorta); 4, excellent (complete absence of motion artefact, strong attenuation of vessel lumen and clear delineation of vessel wall).(14,19) In the event of disagreement between reviewers, the studies were reviewed and a consensus was reached.

The attenuation of the aortic lumen was determined by measuring mean attenuation values (in HU) within circular ROIs drawn at 7 levels of the aorta on axial images: 1, ascending aorta; 2, aortic arch; 3, thoracic descending aorta at the level of the pulmonary trunk; 4, thoracic descending aorta at the diaphragm; 5, abdominal aorta at the level of the renal arteries; 6, abdominal aorta above the bifurcation; 7, right and left common iliac arteries (averaged to one measurement). Each ROI was drawn as large as the vessel lumen allowed, while avoiding atherosclerotic plaques.(20,21)

Image noise was defined as the standard deviation (SD) of the HU attenuation of the adjacent muscle ROI.(20) As previously described, signal-to-noise ratio (SNR) was calculated as the mean attenuation of the artery divided by the image noise per level [$SNR = HU_{vessel}/noise$] and contrast-to-noise ratio (CNR) was calculated as the mean attenuation of the artery minus the mean attenuation of the muscle divided by image noise [$CNR = (HU_{vessel} - HU_{muscle})/noise$].(20,22,23)

To account for differences in radiation exposure of the two protocols, CNR of each artery was normalised by effective dose (ED) using the figure of merit (FOM), [$FOM = CNR^2 / ED$].(24)

Statistical analyses were performed using SPSS software (version 20). Continuous variables were expressed as means ± SD using an independent samples *t* test. Categorical variables were expressed as median values using a Mann-Whitney test and percentages using the chi-square test. A p-value of < 0.05 was considered statistically significant.

RESULTS

Table 1 shows the characteristics of the study population. Patients in group 1 (mean age ± SD, 61.7 ± 14.3 years) were younger than those in group 2 (68.2 ± 12.7 years, $p = 0.01$*) but their weight was not significantly different (67.6 ± 17.1 kg versus 63.7 ± 14.6 kg, $p = 0.19$). The CT indications for both groups were similar ($p = 0.05$). The “other” indications for CTAA included assessment of the aortic root in patients with Marfan syndrome (3 patients in group 1) and suspected aortitis (2 patients in group 1 and 6 patients in group 2).

Table 2 shows the scanning parameters and radiation doses of both groups. The tube voltage settings were not significantly different in both groups ($p = 1.00$). The tube current exposure time product (mAs) was significantly lower in group 1 (196.3 ± 24.6) compared with group 2 (217.8 ± 62.7, $p = 0.008$*). Contrast volume was significantly larger in group 1 compared with group 2 (77.3 ± 6.7 mls vs 73.9 ± 8.8 mls respectively, $p = 0.016$*). The CTDI, DLP and effective dose were significantly higher in group 1 compared with group 2. The ED in group 1 was 13.0 ± 1.9 mSv vs 10.6 ± 3.0 mSv in group 2 ($p < 0.001$*).

Image quality of the aortic root valve complex and proximal ascending aorta was significantly better in group 1 (median = 3) than in group 2 (median = 2, $p < 0.001$*), as demonstrated in Table 3. Representative images of the scoring system are shown in Fig. 1. The median grade of the arch and descending thoracic aorta was 4 in both groups and not significantly different. Although the median grade for the abdominal aorta was the same (median = 3), quantitative image quality of group 1 was significantly better than in group 2

(48.1% of patients in group 1 were graded 4 vs 28.6% of patients in group 2 graded 4, $p = 0.03^*$).

The attenuation of the aortic lumen was measured at 7 levels of the aorta. At each level, apart from at the aortic arch, the arterial attenuation, noise, SNR and CNR was better in group 1 than in group 2 (these differences were significant in the abdominal aorta). At the aortic arch, the arterial attenuation in group 1 (399.2 ± 87.5) was less than in group 2 (404.3 ± 79.7) and the noise, SNR, CNR and FOM were similar. These values in the aortic arch were not statistically significant.

The values measured at 7 levels of the aorta were averaged to one measurement and are presented in Table 4. The mean arterial attenuation in group 1 (406.6 ± 95.6 HU) was significantly higher than in group 2 (392.7 ± 84.5 HU, $p = 0.03^*$). There was significantly less noise in group 1 (13.1 ± 4.9 HU) compared with group 2 (14.8 ± 9.0 HU, $p < 0.001^*$). Overall, the SNR and CNR was significantly better in group 1 than in group 2 (35.5 ± 16.1 vs 30.6 ± 13.0, $p < 0.001^*$; and 30.4 ± 14.6 vs 26.6 ± 11.9, $p < 0.001^*$ respectively). The FOM, which is a measure of image quality independent of radiation dose, tended to be higher in group 1 (90.1 ± 93.4) than in group 2 (87.9 ± 94.3) although this was not statistically significant ($p = 0.74$).

Contrast variation, which is defined as the difference in attenuation between the ascending aorta and the infrarenal abdominal aorta, in group 1 (3.16 ± 69.8) and group 2 (25.0 ± 93.2) was not significantly different ($p = 0.06$).

DISCUSSION

A previous study by Bolen et al. has shown that an ECG-triggered CTAA protocol on a dual source scanner results in better image quality and reduced radiation dose.(14) However, dual source scanners may not be easily available compared with single source CT scanners due to cost. The aim of this study was to compare radiation dose estimates and image quality of ECG-triggered versus non-ECG-triggered CTAA as this has not been previously compared on single source CT scanners.

In this study, we found that ECG-triggered CTAA was superior to non-ECG-triggered CTAA in terms of image quality and there was significant reduction in noise and increase in arterial attenuation. The difference in image quality was most significant at the aortic root and ascending aorta, which is consistent with the findings by Bolen et al. Accurate assessment of the aortic root is of utmost importance in conditions, such as Stanford Type A dissection when it is important to ascertain if the dissection flap extends into the coronary arteries. Another important application is in pre-procedural planning where aortic root dimensions need to be accurate for device sizing.(13,25,26)

Interestingly, in the ECG-triggered group, arterial attenuation was better and did not show significant variation along its length despite the longer scan time. This may be partially attributed to a significantly larger contrast medium volume in group 1 and better contrast medium bolus timing, allowing image capture during a phase of more concentrated intraluminal contrast. The increased contrast volume in group 1 is related to the increased scan time for ECG-triggered studies.

Homogenous contrast enhancement is of clinical significance as it allows accurate imaging of the root without compromising detail further downstream in the aorta and its major branches. This is especially important when assessing the extent of aortic disease in dissection or atherosclerosis.

While ECG-triggered CTAA on a single source scanner was shown in our study to be superior in image quality, its ubiquitous use in daily practice is limited by a few factors.

Of particular significance, there is an increased radiation burden (approximately 23% increase in our study). While increased CTDI and estimated radiation dose in group 1 may be partially attributed to increased patient weight (although weight was not significantly different),(27) the increased radiation dose is probably related to difference in gantry rotation time of each protocol, in an attempt to minimise image noise (noise level was overall better in group 1 compared with group 2 in our study).

A faster gantry rotation time is required for ECG-triggered studies as it minimizes motion artefacts and mis-registration by avoiding the use of redundant data. This results in better temporal resolution. On our 256-slice CT scanner, the gantry rotation times for an ECG-triggered protocol and non-ECG-triggered protocol are 0.27 sec and 0.50 sec respectively. To achieve the same level of noise, a similar tube current-time product value (mAs) should be used. To achieve similar mAs values in both protocols, the scanner typically gives a much higher mA value in the ECG-triggered protocol. The estimated value is 833 mA for the ECG-triggered protocol and 233 mA for the non-ECG-triggered protocol. The use of similar mAs but higher mA results in a higher dose, as dose is proportional to the mA value. Thus for a single-source multidetector CT scanner, better temporal resolution in an ECG-triggered CTAA comes at a price of a higher radiation dose, as demonstrated in our study.(28)

This contrasts with the findings by Bolen et al. on a dual source CT scanner, in which the estimated effective radiation dose was significantly lower in their patient group 1 (scanned with an ECG-triggered high-pitch helical mode protocol) than in patient group 2 (scanned with non–ECG-synchronized standard-pitch helical mode protocol). This reduction in radiation dose in their ECG-triggered group could be related to the nonoverlapping acquisition associated with high pitch CT. This may account for the higher measured noise levels in group 1 compared with group 2 in the Bolen et al study.

Balancing radiation dose and image noise is an important consideration given the heightened awareness regarding radiation exposure during medical imaging.(29) For patients on follow up for aortic conditions, serial CTAA is required, often at yearly intervals.(30,31) In patients with acute aortic dissection and recent aortic intervention, more aggressive imaging surveillance is recommended.(32,33) This results in a significant increase in radiation burden. Within the 6-month period of our study, 12 patients in our cohort underwent repeat studies, of which the most was 4 CTAAs in a 6-month period.

Other factors limiting the use of ECG-triggered technique are that the overall procedure takes longer, due to time spent on cardiac-gating and placement of ECG leads, which makes it challenging to perform in an emergency setting with a deteriorating patient.

There are a few limitations in our study. This was a retrospective study with small numbers, so patients were not randomly assigned to either imaging protocol. The protocol for each patient was determined during a vetting process by radiology residents, based on the history provided by the requesting clinician. There was thus a degree of bias regarding which protocol was selected for each patient.

A clinical history suggesting aortic root / ascending aorta involvement (for example "Stanford type A interposition graft repair done") was usually assigned to an ECG-triggered protocol. However, this was not always the case if inadequate clinical history was provided or the request was misinterpreted by the resident – some patients who had prior ascending root repair were scanned with a non-ECG-triggered protocol while some patients with abdominal aorta stents and no aortic root pathology were scanned with an ECG-triggered protocol. Selection of a protocol is thus very dependent on the information provided by the requesting clinician and is also influenced by the experience of the radiology resident.

In conclusion, our study demonstrates that ECG-triggered CTAA on a single source scanner results in superior image quality and better vessel attenuation of the aortic root and ascending aorta, but a higher radiation dose of approximately 23% compared with non-ECG-triggered CTAA. It should be used when specifically assessing aortic root and ascending aorta pathology, in particular in assessing suspected acute aortic syndrome as recommended by the British Society of Cardiovascular Imaging (BSCI)/British Society of Cardiovascular CT

(BSCCT).(34) Understanding these different imaging protocols for the aorta and their implications will allow the clinician and radiologist to balance conflicting goals of improving image quality and minimising radiation burden to optimise patient care.

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Table 1: Patient demographics and indications for CT angiography of the aorta (CTAA).

Characteristic	Group 1 (*n*=77)	Group 2 (*n*=49)	*p*
Sex, no. (%) of patients			0.20
Male	57 (74)	31 (63)	
Female	20 (26)	18 (37)	
Age	61.7 ± 14.3	68.2 ± 12.7	0.01*
Weight (kg)	67.6 ± 17.1	63.7 ± 14.6	0.19
Indication for CTAA, no. (% of patients)			0.05
Atherosclerosis/ stenosis	5 (6.5)	4 (8.2)	
Known aneurysm	7 (9.1)	15 (30.6)	
Known dissection	2 (2.6)	4 (8.2)	
Follow up imaging after aortic repair or grafting	51 (66.2)	16 (32.7)	
Suspected aortic syndrome	7 (9.1)	4 (8.2)	
Other	5 (6.5)	6 (12.2)	

*p < 0.05, statistically significant.

Table 2: Scanning Parameters

Scanning parameter	Group 1 (*n*=77)	Group 2 (*n*=49)	*p*
Tube voltage setting, no. (% of patients)			1.00
100kV	76 (98.7)	49 (100)	
120kV	1 (1.3)	0 (0)	
mAs†	196.3 ± 24.6	217.8 ± 62.7	0.008*
CTDI‡ (mGy)	12.4 ± 1.9	9.1 ± 2.6	<0.001*
DLP§ (mGy x cm)	765.8 ± 112.4	624.1 ± 174.8	<0.001*
Effective dose (mSv)	13.0 ± 1.9	10.6 ± 3.0	<0.001*
Contrast volume (mls)	77.3 ± 6.7	73.9 ± 8.8	0.016*

*p < 0.05, statistically significant. †mAs – Tube current exposure time product. ‡CTDI - Volume CT dose index. §DLP – Dose length product

Table 3: Qualitative assessment of image quality

Grading at each level, no. (%) of patients	Group 1 (*n*=77)	Group 2 (*n*=49)	*p*
Aortic valve root complex and proximal ascending aorta			
1	0 (0)	4 (8.2)	
2	1 (1.3)	36 (73.5)	
3	39 (50.6)	8 (16.3)	
4	37 (48.1)	1 (2.0)	
Median	3	2	<0.001*
Arch and descending thoracic aorta			
1	0 (0)	0 (0)	
2	1 (1.3)	1 (2.0)	
3	22 (28.6)	13 (26.5)	
4	54 (70.1)	35 (71.4)	
Median	4	4	0.899
Abdominal aorta			
1	0 (0)	0 (0)	
2	0 (0)	0 (0)	
3	40 (51.9)	35 (71.4)	
4	37 (48.1)	14 (28.6)	
Median	3	3	0.031*

*p < 0.05, statistically significant.

Table 4: Quantitative evaluation of image quality (average)

	Group 1 (*n*=77)	Group 2 (*n*=49)	*p*
Arterial attenuation (HU†)	406.6 ± 95.6	392.7 ± 84.5	0.024*
Noise (HU)	13.1 ± 4.9	14.8 ± 9.0	0.002*
SNR‡	35.5 ± 16.1	30.6 ± 13.0	0.000*
CNR§	30.4 ± 14.6	26.6 ± 11.9	0.000*
FOM¶	90.1 ± 93.4	87.9 ± 94.3	0.735

*p < 0.05, statistically significant. †HU – Hounsfield unit. ‡SNR – Signal-to-noise ratio. §CNR – Contrast-to-noise ratio. ¶FOM – Figure of merit

FIGURE

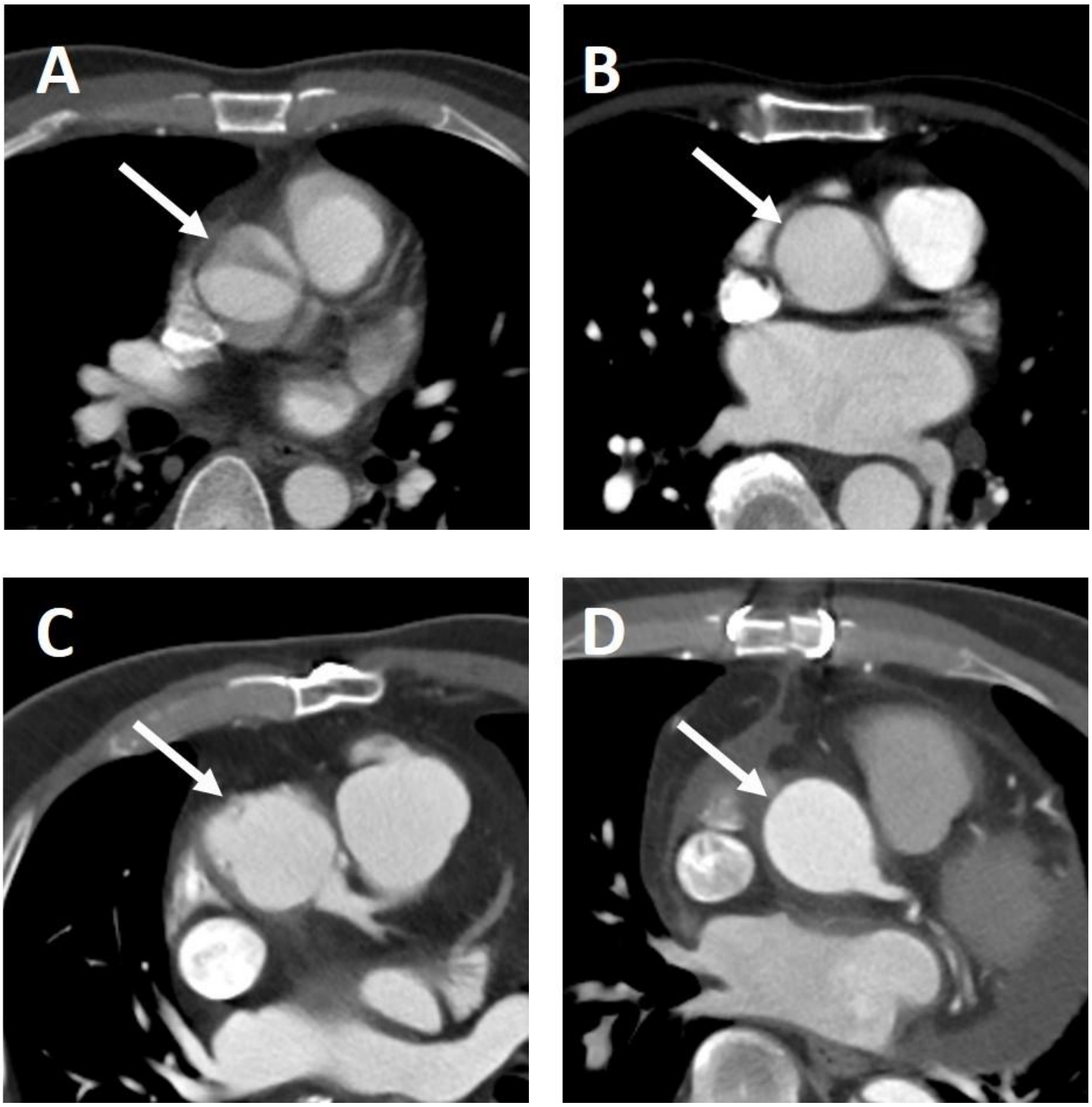

Fig. 1: Axial CT images of 4 different patients illustrating aortic quality scoring at the aortic valve root complex (arrows). A - non-diagnostic (score 1); B - marked artefacts but adequate (2); C - good with mild artefacts (3); D - excellent with no artefacts (4).