INTRODUCTION

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

For the requesting clinician, understanding the different imaging protocols for the aorta, in particular, those of electrocardiogram (ECG)-triggered and non-ECG-triggered CTAA, 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 preset 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.\(^5\)

METHODS: We retrospectively assessed the data of 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 cm and 13.0 ± 1.9 mSv, respectively. These were significantly higher compared to group 2 values (9.1 ± 2.6 mGy, 624.1 ± 174.8 mGy cm and 10.6 ± 3.0 mSv, respectively) \((P < 0.001)\). Qualitative assessment showed the 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 to 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
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, which results in false-positive diagnoses or limits 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 CTAA requires longer acquisition time as compared to non-ECG-triggered CTAA. However, it has 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 aortic root and extension in relation to the coronary ostia.\[12,13\]

ECG-triggered CTAA on a dual-source CT scanner results in higher-quality images of the aortic root and ascending aorta with good contrast enhancement and decreased estimated radiation dose compared to 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, 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 two 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, OH, USA). This has a detector collimation of $128 \times 0.625$ mm with double $z$-sampling, a spatial resolution of $0.625$ mm, $0.27$ s gantry rotation time and temporal resolution of $135$ ms.

All examinations were obtained in a craniocaudal direction from the thoracic inlet to the ischial tuberosities. Patients had an $18$ G cannula placed either in the antecubital fossa or in the dorsum of the hand. No medications were administered for heart rate or rhythm control before 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 the total scanning time, $50$–$80$ mL of non-ionic contrast medium (Omnipaque 350; GE Healthcare, Chicago, IL, USA) was injected at a flow rate of $4$ mL/s, 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 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 dataset, which is important for preoperative 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 was adjusted to include the lateral skin borders tightly, as a small field of view leads to increased $z$-coverage.\[15\] For non-ECG-triggered studies, data were acquired in a 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, OH, 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 fourth-generation advanced iterative reconstruction (iDOSE$^{\text{4}}$; level 4). A medium soft-tissue kernel was used, and the image matrix size was set at $512 \times 512$. All images were transferred to a thin-client server (Intellispace Portal 5.0; Philips Healthcare, Cleveland, OH, 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 \( E_{\text{DLP}} \) to DLP using the following formula: \( ED \ (\text{mSv}) = DLP \times E_{\text{DLP}} \). According to the European guidelines on quality criteria for computer tomography, we used an \( E_{\text{DLP}} \) 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 to simplify the calculation of ED obtained from a thoracoabdominal CTAA. The ED 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 and reviewer 2, 5 years’ cardiac radiology experience), who were blinded to the gating status of the study. The aorta was assessed in three different segments: (a) the aortic root and ascending aorta, (b) the descending thoracic aorta, and (c) the abdominal aorta. The reviewers gave each segment an overall grade according to the following scale: grade 1: non-diagnostic (impaired image quality that precludes appropriate evaluation due to severe motion artefacts, extensive atherosclerotic calcification, severe image noise or insufficient contrast); grade 2: adequate (reduced image quality because of artefacts due to motion, image noise or low contrast attenuation); grade 3: good (presence of artefacts caused by motion, image noise, atherosclerotic calcifications or low contrast, but fully preserved ability to assess the aorta); and grade 4: excellent (complete absence of motion artefact, strong attenuation of the vessel lumen and clear delineation of the 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 seven levels of the aorta on axial images: level 1: ascending aorta; level 2: aortic arch; level 3: thoracic descending aorta at the level of the pulmonary trunk; level 4: thoracic descending aorta at the diaphragm; level 5: abdominal aorta at the level of the renal arteries; level 6: abdominal aorta above the bifurcation; and level 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 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 (\( \text{SNR} = \frac{\text{HU}_{\text{vessel}}}{\text{noise}} \)), 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 (\( \text{CNR} = \frac{\text{HU}_{\text{vessel}} - \text{HU}_{\text{muscle}}}{\text{noise}} \)).\(^{20,22,23}\) To account for differences in radiation exposure of the two protocols, CNR of each artery was normalised by ED using the figure of merit (FOM) (\( \text{FOM} = \text{CNR}^2 / \text{ED} \)).\(^{24}\)

Statistical analyses were performed using IBM SPSS Statistics version 20 (IBM Corp, Armonk, NY, USA). Continuous variables were expressed as mean ± SD using an independent samples t-test. Categorical variables were expressed as median using a Mann–Whitney test, and percentages using the chi-square test. A \( P \) value < 0.05 was considered statistically significant.

**RESULTS**

Table 1 shows the characteristics of the study population. Patients in group 1 were younger than those in group 2 (mean 61.7 ± 14.3 vs. 68.2 ± 12.7 years, \( P = 0.01 \)), but their weight was not significantly different (mean 67.6 ± 17.1 vs. 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 (three patients in group 1) and suspected aortitis (two patients in group 1 and six patients in group 2).

Table 2 shows the scanning parameters and radiation doses of the two groups. The tube voltage settings were not significantly different in both groups (\( P = 1.00 \)). The tube current exposure time product was significantly lower in group 1 than in group 2 (196.3 ± 24.6 vs. 217.8 ± 62.7 mAs, \( P = 0.008 \)). Contrast volume was significantly higher in group 1 compared to group 2 (77.3 ± 6.7 vs. 73.9 ± 8.8 mL, respectively, \( P = 0.016 \)). The CTDI\(_{\text{vol}}\), DLP and ED were significantly higher in group 1 than in group 2; ED in group 1 and 2 was 13.0 ± 1.9 and 10.6 ± 3.0 mSv, respectively (\( P < 0.001 \)).

| Characteristic                      | Group 1 (n=77) | Group 2 (n=49) | \( P \) |
|------------------------------------|----------------|----------------|-------|
| Gender                             |                |                | 0.20  |
| Male                               | 57 (74)        | 31 (63)        |       |
| Female                             | 20 (26)        | 18 (37)        |       |
| Age (yr)                           | 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                |                |                | 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. CTAA: computed tomography angiography of the aorta, SD: standard deviation.
Image quality of the aortic root valve complex and the proximal ascending aorta was significantly better in group 1 (median 3) than in group 2 (median 2, \( P < 0.001 \)), as shown in Table 3. Representative images of the scoring system are shown in Figure 1. The median grade of the arch and the 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 vs. 28.6% of patients in group 2 were graded 4, \( P = 0.03 \)).

The attenuation of the aortic lumen was measured at seven levels of the aorta. At each level, apart from the aortic arch, the arterial attenuation, noise, SNR and CNR were 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 seven levels of the aorta were averaged to one measurement and are presented in Table 4. The mean arterial attenuation in group 1 was significantly higher than in group 2 (406.6 ± 95.6 vs. 392.7 ± 84.5 HU, \( P = 0.03 \)). There was significantly less noise in group 1 as compared to group 2 (13.1 ± 4.9 vs. 14.8 ± 9.0 HU, \( P < 0.001 \)). Overall, SNR and CNR were significantly better in group 1 than in group 2 (35.5 ± 16.1 vs. 30.6 ± 13.0, \( P < 0.00 \), and 26.6 ± 11.9, \( P < 0.001 \), respectively). The FOM, which is a measure of image quality independent of the 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, was not significantly different on comparing group 1 (3.16 ± 69.8) to group 2 (25.0 ± 93.2, \( P = 0.06 \)).

**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. However, dual-source scanners may not be as easily available as 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 CTAAs, as this has not been previously compared on single-source CT scanners.

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

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.

Homogeneous 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 CTAAs 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 is the 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), 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 to group 2 in our study).

A faster gantry rotation time is required for ECG-triggered studies, as it minimises motion artefacts and misregistration by avoiding the use of redundant data. This results in better temporal resolution. On our 256-slice CT scanner, the gantry rotation times for ECG-triggered protocol and non-ECG-triggered protocol are 0.27 and 0.50 s, respectively. To achieve the same level of noise, a similar tube current-time product value (mAs) should be used. To achieve similar mA 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 higher mA in the ECG-triggered protocol 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 CTA comes at the price of a higher radiation dose, as demonstrated in our study. This contrasts with the findings of 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 a non-ECG-synchronised 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 to group 2 in the study by Bolen et al.

Balancing radiation dose and image noise is an important consideration, given the heightened awareness regarding radiation exposure during medical imaging. For patients on follow-up for aortic conditions, serial CTs are required, often at yearly intervals. In patients with acute aortic dissection and recent aortic intervention, more aggressive imaging surveillance is recommended. 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 four CTAAs in a 6-month period.

Another factor limiting the use of ECG-triggered technique is that the overall procedure takes longer due to the 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 a small number of patients, and 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. Thus, there was a degree of bias in the protocol selected for each patient. A clinical history suggesting...
aortic root/ascending aorta involvement (e.g., ‘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 highly 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% as compared to non-ECG-triggered CTAA. It should be used when specifically assessing aortic root and ascending aorta pathology, in particular, suspected acute aortic syndrome, as recommended by British Society of Cardiovascular Imaging/British Society of Cardiovascular CT.[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.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

REFERENCES
1. Cigarroa JE, Isselbacher EM, DeSanctis RW, Eagle KA. Diagnostic imaging in the evaluation of suspected aortic dissection. Old standards and new directions. N Engl J Med 1993;326:35-43.
2. Balliga RR, Nienaber CA, Bossone E, Oh JK, Isselbacher EM, Sechtem U, et al. The role of imaging in aortic dissection and related syndromes. JACC Cardiovasc Imaging 2014;7:406-24.
3. Holloway BJ, Rosewarne D, Jones RG. Imaging of thoracic aortic disease. Br J Radiol 2011;84:S338-54.
4. Nagpal P, Agrawal MD, Saboo SS, Hedgire S, Priya S, Steigner ML. Imaging of the aortic root on high-pitch non-gated and ECG-gated CT: Awareness is the key! Insights Imaging 2020;11:51.
5. Wu W, Budovec J, Foley WD. Prospective and retrospective ECG gating for thoracic CT angiography: A comparative study. AJR Am J Roentgenol 2009;193:955-63.
6. Earls JP, Berman EL, Urban BA, Curry CA, Lane JL, Jennings RS, et al. Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: Improved image quality and reduced radiation dose. Radiology 2008;246:742-53.
7. Russo V, Garattoni M, Ruia F, Attinà D, Lovato L, Zompatori M. 128-slice CT angiography of the aorta without ECG-gating: Efficacy of faster gantry rotation time and iterative reconstruction in terms of image quality and radiation dose. Eur Radiol 2016;26:359-69.
8. Batra P, Bigoni B, Manning J, Aberle DR, Brown K, Hart E, et al. Pitfalls in the diagnosis of thoracic aortic dissection at CT angiography. Radiographics 2000;20:309-20.
9. Roos JE, Willmann JK, Weishaupt D, Lachat M, Marineck B, Hilfiker PR. Thoracic aorta: Motion artifact reduction with retrospective and prospective electrocardiography-assisted multi-detector row CT. Radiology 2002;222:271-7.
10. Imoto K, Uchida K, Karube N, Yasutsune T, Cho T, Kimura K, et al. Risk analysis and improvement of strategies in patients who have acute type A aortic dissection with coronary artery dissection. Eur J Cardiothoracic Surg 2013;44:419-25.
11. Li Y, Fan Z, Xu L, Yang L, Xin H, Zhang N, et al. Prospective ECG-gated 320-row CT angiography of the whole aorta and coronary arteries. Eur Radiol 2012;22:2432-40.
12. Fujioka C, Horiguchi J, Kiguchi M, Yamamoto H, Kitagawa T, Ito K. Survey of aorta and coronary arteries with prospective ECG-triggered 100-kV 64-MDCT angiography. AJR Am J Roentgenol 2009;193:257-33.
13. Moon MC, Greenberg RK, Morales JP, Martin Z, Lu Q, Dowdall JF, et al. Computed tomography-based anatomic characterization of proximal aortic dissection with consideration for endovascular candidacy. J Vasc Surg 2011;53:942-9.
14. Bolen MA, Popovic ZB, Tandon N, Flamm SD, Schoenhhorn P, Halliburton SS. Image quality, contrast enhancement, and radiation dose of ECG-triggered high-pitch CT versus non-ECG-triggered standard-pitch CT of the thoracoabdominal aorta. AJR Am J Roentgenol 2012;198:931-8.
15. Muenzel D, Noel PB, Dorn F, Dobritz M, Rummenny EJ, Huber A. Coronary CT angiography in step-and-shoot technique with 256-slice CT: Impact of the field of view on image quality, cranio-caudal coverage, and radiation exposure. Eur J Radiol 2012;81:1562-8.
16. European guidelines on quality criteria for computed tomography. 1999. Eur 16262. In: Publications Office of the European Union. Available from: https://op.europa.eu/en/publication-detail/-/publication/2229c9e1-a967-49dc-b169-59ee68605f1a. [Last accessed on 2021 Feb 19].
17. Deak PD, Smal Y, Kalender WA. Multisecton CT protocols: Sex- and age-specific conversion factors used to determine effective dose from dose-length. Radiology 2010;257:158-66.
18. Martin CJ. Effective dose: How should it be applied to medical exposures? Br J Radiol 2007;80:639-47.
19. Bischoff B, Hein F, Meyer T, Hadamitzky M, Martinoff S, Schönig A, et al. Impact of a reduced tube voltage on CT angiography and radiation dose: Results of the PROTECTION I study. JACC Cardiovasc Imaging 2009;2:940-6.
20. Apfaltrer P, Hanna EL, Schoepp UJ, Spears JR, Schoenhhorn SO, Fink C, et al. Radiation dose and image quality at high-pitch CT angiography of the aorta: Intraindividual and interindividual comparisons with conventional CT angiography. AJR Am J Roentgenol 2012;199:1402-9.
21. Schindera ST, Graca P, Patak MA, Abderhalden S, von Allmen G, Ziegler M, et al. Coronal CT: Impact of the field of view on image quality, craniocaudal coverage, and radiation dose. Invest Radiol 2009;44:650-5.
22. Pontana F, Duhamel A, Pagniez J, Flohr T, Faivre JB, Hachulla AL, et al. Awareness is the key! Insights Imaging 2020;11:51.
23. Wu W, Budovec J, Foley WD. Prospective and retrospective ECG gating for thoracic CT angiography: A comparative study. AJR Am J Roentgenol 2009;193:955-63.
24. Erlandsson H, Österdahl P, Norgren L, Wiklund O, Hedin O, et al. Coronary CT angiography in step–and–shoot technique with 256–slice CT: Impact of the field of view on image quality, cranio–caudal coverage, and radiation exposure. Eur J Radiol 2012;81:1562–8.
25. European guidelines on quality criteria for computed tomography. 1999. Eur 16262. In: Publications Office of the European Union. Available from: https://op.europa.eu/en/publication-detail/-/publication/2229c9e1-a967-49dc-b169-59ee68605f1a. [Last accessed on 2021 Feb 19].
26. Deak PD, Smal Y, Kalender WA. Multisecton CT protocols: Sex- and age-specific conversion factors used to determine effective dose from dose-length. Radiology 2010;257:158-66.
27. Martin CJ. Effective dose: How should it be applied to medical exposures? Br J Radiol 2007;80:639-47.
28. Bischoff B, Hein F, Meyer T, Hadamitzky M, Martinoff S, Schönig A, et al. Impact of a reduced tube voltage on CT angiography and radiation dose: Results of the PROTECTION I study. JACC Cardiovasc Imaging 2009;2:940-6.
29. Apfaltrer P, Hanna EL, Schoepp UJ, Spears JR, Schoenhhorn SO, Fink C, et al. Radiation dose and image quality at high-pitch CT angiography of the aorta: Intraindividual and interindividual comparisons with conventional CT angiography. AJR Am J Roentgenol 2012;199:1402-9.
30. Schindera ST, Graca P, Patak MA, Abderhalden S, von Allmen G, Ziegler M, et al. Coronal CT: Impact of the field of view on image quality, craniocaudal coverage, and radiation dose. Invest Radiol 2009;44:650-5.
31. Pontana F, Duhamel A, Pagniez J, Flohr T, Faivre JB, Hachulla AL, et al. Chest computed tomography using iterative reconstruction vs filtered back projection (Part 2): Image quality of low-dose CT examinations in 80 patients. Radiol Eur 2011;21:636-43.
32. Szac–Farkas Z, Strautz T, Patak MA, Kurmann L, Vock P, Schindera ST. Is body weight the most appropriate criterion to select patients eligible for low-dose pulmonary CT angiography? Analysis of objective and subjective image quality at 80 kVp in 100 patients. Eur Radiol 2009;19:1914-22.
33. Usunomiya D, Oda S, Funama Y, Awai K, Nakaura T, Yanaga Y, et al. Comparison of standard- and low-tube voltage MDCT angiography in patients with peripheral arterial disease. Eur Radiol 2010;20:2758-65.
34. Lu TL, Huber CH, Rizzo E, Dehmeski J, von Segesser LK, Qanadli SD. Ascending aorta measurements as assessed by ECG-gated multi-detector computed tomography: A pilot study to establish normative values for transcatheter therapies. Eur Radiol 2009;19:664-9.
35. Matsumoto S, Yamada Y, Hashimoto M, Okamura T, Yamada M, Yashima F, et al. CT imaging before transcatheter aortic valve implantation (TAVI) using variable helical pitch scanning and its diagnostic performance for coronary artery disease. Eur Radiol 2017;27:1963-70.
28. Primak AN, McCollough CH, Bruesewitz MR, Zhang J, Fletcher JG. Relationship between noise, dose, and pitch in cardiac multi-detector row CT. Radiographics 2006;26:1785-94.
29. Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, et al. Exposure to low-dose ionizing radiation from medical imaging procedures. N Engl J Med 2009;361:849-57.
30. McLarty AJ, Bishawi M, Yelika SB, Shroyer AL, Romeiser J. Surveillance of moderate-size aneurysms of the thoracic aorta. J Cardiothorac Surg 2015;10:17.
31. Chaikof EL, Dalman RL, Eskandari MK, Jackson BM, Lee WA, Mansour MA, et al. The Society for Vascular Surgery practice guidelines on the care of patients with an abdominal aortic aneurysm. J Vasc Surg 2018;67:2-77.e2.
32. Iribarne A, Keenan J, Benrashid E, Wang H, Meza JM, Ganapathi A, et al. Imaging surveillance after proximal aortic operations: Is it necessary? Ann Thorac Surg 2017;103:734-41.
33. Chaddha A, Eagle KA, Patel HJ, Deeb GM, Yang B, Harris KM, et al. The clinical impact of imaging surveillance and clinic visit frequency after acute aortic dissection. Aorta (Stamford) 2019;7:75-83.
34. Vardhanabhuti V, Nicol E, Morgan-Hughes G, Roobottom CA, Roditi G, Hamilton MC, et al. Recommendations for accurate CT diagnosis of suspected acute aortic syndrome (AAS)—on behalf of the British Society of Cardiovascular Imaging (BSCI)/British Society of Cardiovascular CT (BSCCT). Br J Radiol 2016;89:20150705.