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Guidelines

Guideline for minimizing radiation exposure during acquisition of coronary artery calcium scans with the use of multidetector computed tomography

A report by the Society for Atherosclerosis Imaging and Prevention Tomographic Imaging and Prevention Councils in collaboration with the Society of Cardiovascular Computed Tomography

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Abstract. Coronary artery calcium (CAC) scanning is an important tool for risk stratification in intermediate-risk, asymptomatic subjects without previous coronary disease. However, the clinical benefit of improved risk prediction needs to be balanced against the risk of the use of ionizing radiation. Although there is increasing emphasis on the need to obtain CAC scans at low-radiation exposure to the patient, very few practical documents exist to aid laboratories and health care professionals on how to obtain such low-radiation scans.

The Tomographic Imaging Council of the Society for Atherosclerosis Imaging and Prevention, in collaboration with the Prevention Council and the Society of Cardiovascular Computed Tomography, created a task force and writing group to generate a practical document to address parameters that can be influenced by careful attention to image acquisition.

Patient selection for CAC scanning should be based on national guidelines. It is recommended that laboratories performing CAC examinations monitor radiation exposure (dose-length-product [DLP]) and effective radiation dose (E) in all patients. DLP should be <200 mGy × cm; E should average 1.0–1.5 mSv and should be <3.0 mSv. On most scanner platforms, CAC imaging should be performed in an axial mode with prospective electrocardiographic triggering, using tube voltage of 120 kVp. Tube current should be carefully selected on the basis of patient size, potentially using chest lateral width measured on the topogram. Scan length should be limited for the coverage of the heart only.

When patients and imaging parameters are selected appropriately, CAC scanning can be performed with low levels of radiation exposure.

Introduction

Coronary artery calcification (CAC) detected by computed tomography (CT) is a recognized surrogate marker of atherosclerosis.[1] CAC correlates with coronary atherosclerotic plaque burden and has been shown to be an independent predictor of coronary events.[2] More importantly, CAC quantification improves risk stratification above and beyond the Framingham Risk Score (FRS)[1] and allows for substantial risk reclassification.[3] In asymptomatic subjects, the absence of coronary calcium has been associated with a very low risk of cardiovascular events in studies with an average follow-up of 5 years.[4,5] The American College of Cardiology/American Heart Association (AHA) Expert Consensus Document (which was written before the publication of most of the aforementioned references) recommends that CAC screening can be considered in subjects with an intermediate risk (FRS, 10%–20%) for future cardiovascular events.[6] The National Institute for Health and Clinical Excellence Guidelines recommend CAC scanning for patients being referred for chest pain evaluation,[7] and a number of consensus documents have recommended CAC quantification in asymptomatic subjects with no history of coronary artery disease (CAD) with intermediate risk on the basis of global risk assessment and in low-risk patients with a family history of CAD.[8]

Although the early detection of coronary atherosclerosis with CAC imaging may enhance risk prediction, the potential benefits of CAC scanning need to be weighed against its potential risks, namely against the risk of exposure to ionizing radiation. In 2006, the AHA issued a consensus statement about the appropriate imaging parameters to reduce radiation dose to patients.[9] If these parameters are applied correctly, mean effective radiation dose (E) associated with a CAC scan should average about 1.0–1.5 mSv and should not exceed 3.0 mSv.

This amount represents slightly less than the amount of radiation the average person receives each year in the United States from natural sources (eg, 3.1 mSv). As a reference, effective doses from typical nonmedical and medical sources of radiation are listed in Appendix A.

Despite these recommendations, a recent report suggested that the "real world" effective radiation dose for this screening test ranges between 0.8 mSv and 10.5 mSv.[10] Although in this report median radiation dose was 2.3 mSv; 2 centers reported radiation doses in excess of 3.6 mSv. In both centers, the high estimates that were observed reflected scan acquisition techniques that are not considered appropriate by contemporary standards. With the use of the mean effective dose of 2.3 mSv, it was estimated that a single CAC scan at age 55 may be expected to result in a lifetime excess risk of 8 and 20 cancers per 100,000 persons for men and women, respectively. This study emphasized the importance of ensuring more standardized techniques for performing CAC scans.

There is emerging evidence that a number of strategies can reduce radiation exposure associated with CAC scanning, while maintaining superior diagnostic image quality and clinical predictive value. Therefore, the objective of the present document is to compile the available current approaches to reduce radiation exposure associated with CAC scanning in a practical guideline that can be implemented in laboratories performing CAC imaging on multidetector CT (MDCT) platforms.

Rationale and background to recommendations

On the basis of the cumulative clinical evidence indicating that CAC scanning can improve risk stratification in the primary prevention setting, the risk-benefit ratio favors CAC quantification in asymptomatic subjects with no previous history of CAD and with intermediate risk of major cardiovascular events, especially if radiation exposure can be minimized. Given the rapid advances in dose-reduction techniques, the Tomographic Imaging Council and the Prevention Council of the Society for Atherosclerosis Imaging and Prevention felt it appropriate and timely to compile available information in a practical document that can be used as a guide by laboratories that perform non–contrast-enhanced CAC scanning.

The guiding principle behind this guideline document was to address all potential variables that can be controlled and influenced by patient selection and appropriate imaging. A Writing Group of the Tomographic Council and the Prevention Council conducted several telephone conferences to determine necessary topics and content. All recommendations are presented as Minimum Requirements and Optional Recommendations. Minimum Requirements are strategies the Committee felt every laboratory performing CAC scans should adhere to, whereas Optional Recommendations provide further, more sophisticated strategies or more stringent recommendations. When available, recommendations are supported by published literature; controversial items were decided by consensus.

General recommendations for CT laboratories performing non–contrast-enhanced CAC scans

Recommendations for systematic monitoring of radiation dose

1. ***Minimum Requirements*. Laboratories should record radiation dose in each patient (dose-length-product [DLP] in units of mGy × cm and effective radiation dose [E] in units of mSv) and should determine average values in each quarter for all consecutive patients. Average and maximum radiation dose from each quarter should be reviewed by the laboratory, in the context of recommended target radiation dose and image noise values (see below).**
2. ***Optional Recommendations*. Laboratories may measure image noise in 30 patients in each quarter (10 each of small, medium, and large patients [see below]) and should review average image noise in each of the 3 patient categories in the context of target image noise values (see below). A practical guide to measuring image noise is provided in Appendix B and Appendix C.**

The calculation of E on the basis of DLP is described in Appendix D.

Recommendations for radiation dose targets

1. ***Minimum Requirements*. Average DLP should not exceed approximately 200 mGy × cm or, alternatively, E should average 1.0–1.5 mSv and should not exceed 3.0 mSv in laboratories that routinely perform CAC scanning.**
2. ***Optional Recommendations*. It is expected that if tube current settings are chosen to optimize image noise (see below), average DLP will not exceed 200 mGy × cm, and E will average 1.0–1.5 mSv and will not exceed 3.0 mSv.**

The principle of as low as reasonably achievable should be applied to CAC scanning, similar to other medical imaging procedures that use ionizing radiation. Because lifetime risk of cancer is determined by the cumulative radiation dose, it is critical that radiation exposure associated with each procedure is minimized. With the use of various dose-reduction approaches, average effective radiation estimates are approximately 1.0–2.0 mSv for prospectively triggered coronary calcium CT scans but can be significantly higher (eg, >3.0 mSv) for scans using a helical acquisition with retrospective gating.[10,11] When appropriate techniques are used, radiation dose (E) in a laboratory should not exceed 3.0 mSv; for axial mode with prospective electrocardiographic (ECG) triggering, the preferred acquisition method, E should be <2.0 mSv.

An image noise target, rather than a radiation dose target, may be even more important to ensure that small- and medium-sized patients do not receive unnecessary radiation doses and that large patients receive sufficient doses for accurate calcium quantification.[12] The principle is that tube current can be optimized to achieve predetermined image noise targets in small, medium, and large patients (see below), and such tube current settings will result in predictable average radiation doses, typically below 3.0 mSv. It is important to point out that optimal tube current will be higher in large patients to achieve acceptable image quality. Although this will result in higher calculated E values, the true increase in E is likely less, because of increased scatter and attenuation in large patients.

Recommendation for radiation dose reporting

1. ***Minimum Requirements*. Laboratories should record radiation dose in each patient (DLP in units of mGy × cm and E in units of mSv) and should determine average values in each quarter for all consecutive patients.**
2. ***Optional Recommendations*. DLP and, alternatively, E may be included in the clinical report.**

As mentioned above, it is critical for CT laboratories to record radiation exposure and dose (DLP and E) in all patients. It should be noted, however, that the reported DLP value represents the total radiation energy absorbed by a standard phantom scanned with the same protocol used for a given patient. Subsequently, the reported DLP estimate differs from the patient's actual DLP to the extent that the patient differs from a standard phantom.

There is controversy as to whether radiation dose information should be included in the clinical report. Although some institutions routinely report radiation doses, it is not currently mandatory.[13] The advantages of including the dose information in the report is that it communicates transparency, indicates that the laboratory is conscious of radiation dose, fosters self-monitoring, and may improve overall quality. Furthermore, referring physicians may be able to determine risk-benefit ratio in their population on the basis of this information, and patients may be able to track their cumulative radiation dose over time. However, including dose information in the report may generate unnecessary anxiety. Nevertheless, it is anticipated that including dose information in the clinical report may become a national requirement (http://www.fda.gov/Radiation-EmittingProducts/RadiationSafety/RadiationDoseReduction/ucm199994.htm).[14]

The Writing Committee included either the reporting of DLP or E as optional. The Writing Committee recognizes that reporting DLP is more meaningful on the basis of its measurement; however, E is a better known concept; therefore, reporting E may be more meaningful to referring physicians and the general public.

Specific recommendations for CAC imaging

Patient selection

1. ***Minimum Requirements*. Referral for CAC scanning should be based on current consensus documents and clinical practice guidelines, and laboratories should monitor appropriateness of referrals to the laboratory. Women with childbearing potential should be asked about the possibility of pregnancy, and CAC scanning should not be performed if pregnancy cannot be excluded.**
2. ***Optional Recommendations*. Patients without appropriate indications for CAC scanning may be offered an optional screening test**.

Indications for CAC scanning have been published in appropriate use criteria and expert consensus statements,[6,8] and the details are beyond the scope of the current document. In general, CAC scanning is appropriate in asymptomatic subjects with no history of CAD, with intermediate risk of cardiovascular events on the basis of global risk assessment, or in low-risk patients with a family history of CAD. There is no further benefit in studying patients at high risk or with present clinical disease (eg, previous myocardial infarction, stent, or coronary artery bypass), and such scans should be avoided.

Few absolute exclusion criteria exist for CAC scanning; however, several factors can affect scan performance and should be considered. Patients should be able to follow instructions and perform an adequate breathhold. A high body mass index may increase image noise and may necessitate alteration of scan parameters, specifically increasing tube current and, thereby, increasing radiation exposure.[6,12,15] High heart rates and arrhythmias may lead to decreased accuracy of calcium scores and heart rate control with β-blockers or calcium channel blockers may be considered in such cases (see below).[16–18]

Patient preparation

1. ***Minimum Requirements*. Patients may continue to take their usual medications. Practicing the breathhold before image acquisition may be helpful**.
2. ***Optional Recommendations*. Oral β-blockers before the scan may be considered if the heart rate is elevated (eg, >75 beats/min)**.[16]

Scan mode and ECG synchronization

1. ***Minimum Requirements*. The ECG-referenced acquisition mode requiring the least radiation exposure for a given scanner should be selected. For most systems this will be a prospective, ECG-triggered axial (also known as sequential, step-and-shoot, or volumetric) mode. For dual-source systems in which high-pitch acquisition mode is available, a prospectively ECG-triggered helical (also known as spiral) mode may be appropriate. Retrospectively ECG-gated helical (or spiral) acquisition modes should be avoided on all systems, except in patients with extremely high or irregular heart rates.**[9]
Typically, data should be acquired or reconstructed during mid-diastole (eg, 70% of the cardiac cycle). For higher heart rates (eg, >75 beats/min), data from systole may be more appropriate.

For prospectively triggered coronary CAC scans, estimated average effective dose is approximately 1.0–1.5 mSv, whereas for retrospectively gated scans, estimated dose is approximately 3.0 mSv, as reported by the AHA Writing Group in ionizing radiation dose in cardiac imaging.[19]

Tube voltage selection

1. ***Minimum Requirements*. For routine clinical CAC imaging, a peak tube voltage of 120 kVp should be used**.

It is now generally accepted that MDCT imaging, at a standard peak tube voltage of 120 kVp, is equivalent to electron-beam CT for quantification of coronary calcium.[20,21] This tube voltage allows the use of the standard minimum calcium threshold of 130 Hounsfield units (HU) for quantifying the "area-density" (Agatston) and volume scores.[22,23]

It has recently been shown that coronary calcium scoring with a 100-kVp scan protocol is equivalent to scanning with 120 kVp, with a significant reduction in radiation dose; however, this requires calculation of a new calcium threshold on the basis of phantom measurements.[23] Potentially, lowering the tube current at 120 kVp may achieve similar results without requiring calculation of a new threshold; however, this needs further study. Therefore, the general recommendation at this time is to use standard 120 kVp for coronary calcium scoring with MDCT. Use of 100 kVp scans may be acceptable if a laboratory uses a new threshold for calcium, based on phantom measurements with each scanner used.

Tube current selection

1. ***Minimum Requirements*. Manufacturer-recommended default tube current values should be adjusted on the basis of patient size with the use of visual assessment, body weight, body mass index, or the chest lateral width, as measured on the chest radiograph (Fig. 1). Patient size-specific tube current values can be determined through experience for a given scanner and scan protocol, by monitoring image noise and adjusting tube current as necessary to achieve target image noise values across patient sizes (see Appendixes B and C).**
2. ***Optional Recommendations*. Experimentally derived scanner- and patient size-specific tube current values can be determined for any system with access to specially designed phantoms.**

The principle behind patient size-based tube current selection is that in a certain-sized patient, predetermined acceptable noise levels can be achieved by prescribing an appropriate tube current on any scanner system. On the basis of previous work, acceptable levels of noise have been determined in small-, medium-, and large-sized patients[12] and are summarized in Table 1.

Previous work has suggested dividing patients into 3 size categories on the basis of lateral chest width, as measured on a routine, anteroposterior chest radiograph (small, <32 cm; medium, 32–38 cm; large, >38 cm). Reasonable noise targets were defined for each size category (Table 1). These noise targets can be achieved across patient sizes with appropriately selected tube currents (Fig. 1). A practical toolkit for patient size–based determination of tube current is provided in Appendixes B and C.

Table 1 Recommended noise targets in small, medium, and large patients, based on chest lateral width

	Small	Medium	Large
Chest lateral width, cm	<32	32–38	>38
Noise target, HU	20	20	23

Scan length prescription

1. ***Minimum Requirements*. The scan length should be minimized to include the entire coronary tree, without risking the possibility of missing a portion of the coronary vasculature that would necessitate a repeat scan.**

There is a general principle in CT: the greater the scan length, the greater the radiation exposure. Therefore, scan length should be limited to the extent that is necessary to address the question posed. In case of a standard CAC scan, the length should be sufficient to include the entire coronary vasculature and not include other areas, such as the aortic arch. Typically, the scan length is planned with the use of the scout view as a reference; it usually extends from 1 cm below the carina to just below the cardiac apex. In cases in which the apex is not well visualized, the lower scan border could be set at the level of the left lateral pleural recess (Fig. 2).

Reconstructed slice thickness

1. ***Minimum Requirements*. Slices should be reconstructed with 3-mm thickness. The widest beam collimation that allows reconstruction of 3-mm slices should be selected.**

A reconstructed slice thickness of 3 mm is most appropriate for the quantification of CAC, using the current area-density method.[22] Although acquisition of thinner slices may increase the reproducibility of CAC scores, acquisition of thicker slices will be associated with a lower radiation dose.

Conclusions

CAC scanning provides incremental risk stratification in asymptomatic subjects without previous history of CAD. Because CAC scanning is performed as a screening technique in primary prevention, it is imperative that such scans are performed with the lowest radiation exposure possible to the patient.

Patient selection should be based on national guidelines. Laboratories performing CAC scans should monitor radiation exposure and estimated radiation dose to each patient and should review the data on a regular basis. In general, average DLP and average radiation dose should not exceed 200 mGy × cm and 3.0 mSv, respectively.

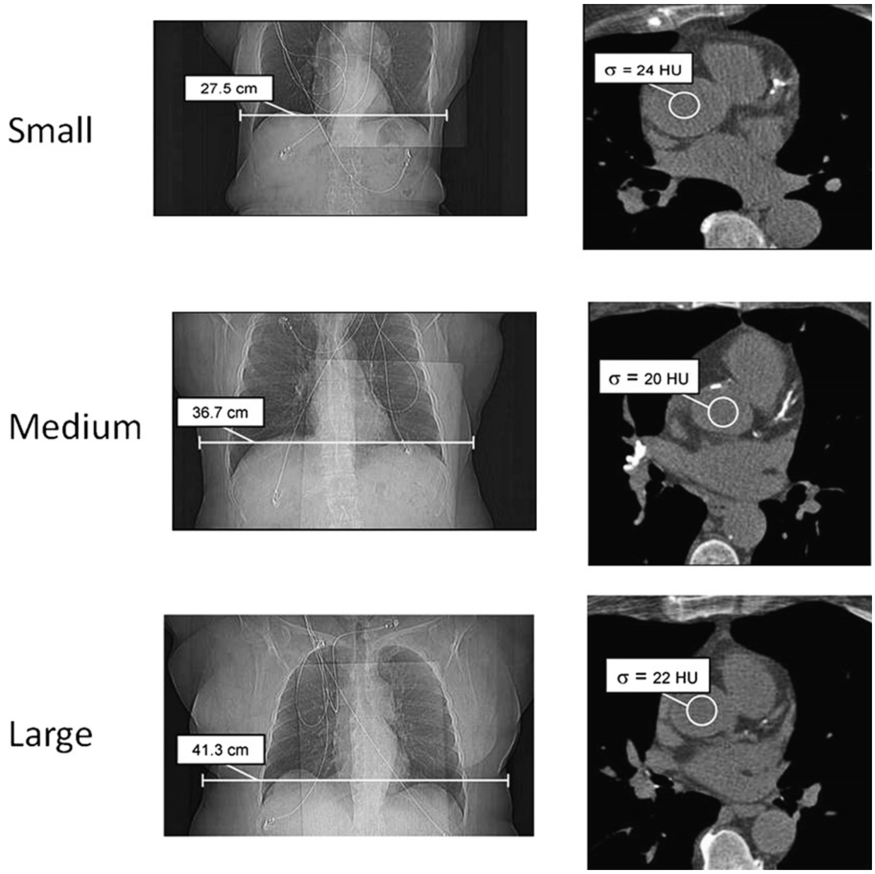

Figure 1 Measurement of chest lateral width on the topogram and determination of noise level in the ascending aorta. Chest lateral width is measured on the topogram from skin to skin at the level of the left hemidiaphragm, as shown in the images on the left. Noise levels are measured in axial slices on the non-contrast CT dataset as shown in the images on the right, by placing a circular region of interest in the ascending aorta at the level of the coronary ostia. Image noise is expressed as the standard deviation of the attenuation values within the region of interest, in Hounsfield units.

When patients and image acquisition strategies are selected appropriately, it is anticipated that radiation exposure and dose will fall in the ranges described above. In general, on most scanner platforms, CAC imaging should be performed in an axial mode with prospective electrocardiographic triggering, using a tube voltage of 120 kVp. Tube current should be carefully selected on the basis of patient size.

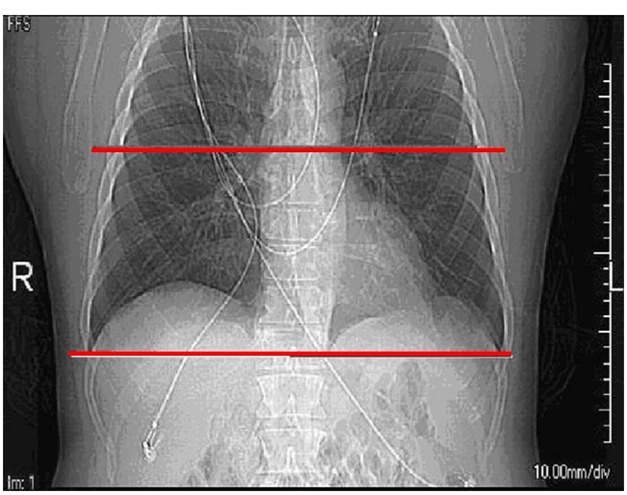

Figure 2 Prescribing scan length on the basis of heart size on the topogram. Scan length is planned with the use of the scout view as a reference; it usually extends from 1 cm below the carina to just below the cardiac apex.

With the use of these approaches, we anticipate that the use of CAC scanning in the primary prevention setting will continue to improve patient care with a favorable risk-benefit ratio, by providing improved risk stratification at acceptably low levels of radiation exposure.

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Summary of Recommendations

Recommendations for CT laboratories performing scans	
Self-monitoring	Radiation dose should be recorded in all consecutive patients, and average dose should be reviewed quarterly in the context of radiation dose and image noise targets
Radiation dose targets	In general, average DLP should not exceed 200 mGy $\times$ cm or, alternatively, E should average 1.0–1.5 mSv and should not exceed 3.0 mSv in laboratories that routinely perform CAC scans
Dose reporting	DLP and, alternatively, E should be recorded for each patient and may be included in the clinical report

Specific recommendations for CAC imaging	
Patient selection	Patient selection should be based on current clinical guidelines and consensus documents; in general, asymptomatic subjects with no prior CAD are best candidates
Patient preparation	Women who are possibly pregnant should not undergo CAC scanning
Scan mode and ECG	ECG-triggered axial (sequential, step-and-shoot, or volumetric) scans should be used; in patients with very high heart rates, triggering in systole or retrospective gating may be used
EKG synchronization	Prospective EKG triggering should be used, typically triggering in mid-diastole; in patients with higher heart rates, triggering in systole or retrospective gating may be used
Tube voltage	For routine clinical CAC imaging, a peak tube voltage of 120 kVp should be used
Tube current	Manufacturer-recommended default tube current should be modified on the basis of patient size and attainment of desired image noise
Scan length	Scan length should be as narrow as possible to include the entire coronary tree, without risking missing a portion of the coronary vasculature
Reconstruction slice thickness	Images should be reconstructed at 3–mm slice thickness and, depending on the manufacturer, the widest collimation should be used that allows a 3-mm reconstruction

Appendix A. Typical effective radiation doses associated with non-medical and medical exposures[24]

	All	Men	Women
Mean annual background radiation in the United States (excluding medical sources), mSv	3.5		
EBCT, mSv		1.5	2.0
4 MDCT coronary angiography, mSv	11–13		
16 MDCT coronary angiography, mSv	9.8		
64 MDCT coronary angiography, mSv	8.6		
Invasive x-ray coronary angiography, mSv		2.1	2.5
CT chest, mSv	5–7		
CT head, mSv	1–2		
Radionuclide Single-Isotope Myocardial Perfusion Study, mSv	8–12		
Mammography, mSv			0.4–1.0
Chest radiography, mSv	0.02–0.1		

EBCT, electron beam CT.

Appendix B. Toolkit for determining tube current and monitoring noise levels for CT laboratories

1. Retrieve 10–15 CAC studies from patients in each of 3 size categories (small, medium, and large). To determine patient size:
   a. Measure lateral chest width on the anteroposterior radiograph, by measuring the skin-to-skin distance at the top of the right dome of the liver (Fig. 1)
   b. Assign to size category:
      i. Small, <32 cm
      ii. Medium, 32–38 cm
      iii. Large, >38 cm
2. Measure image noise in each patient by placing a circular region of interest (ROI) in a cross-section of the ascending aorta, at the level of the coronary arterial ostia (Fig. 1). The ROI should be about two-thirds the size of the aortic cross-section. Image noise is defined as the standard deviation (SD) of the signal within the ROI, expressed in Hounsfield units. Average the image noise within the small, medium, and large patient groups.
3. Record the DLP (in mGy × cm) and E (in mSv) from the same patients, and average the values within each patient group.
4. Record the tube current used for each patient and average values within each patient group.
5. If average image noise in any of the 3 size categories is *less* than the target noise level (small patients, 20 HU; medium patients, 20 HU; large patients, 23 HU) *decrease* tube current in the patient size category and repeat the measurements in another group of 10–15 patients with the new tube current settings. Repeat the cycle until target noise level is achieved. Note average radiation dose with each set of tube current settings.
6. If average image noise in any of the 3 size categories is *more* than the target noise level, *increase* tube current in the patient size category and repeat the measurements in another group of 10–15 patients with the new tube current settings. Repeat the cycle until target noise level is achieved. Note average radiation dose with each set of tube current settings.

A worksheet to aid in this process is provided in Appendix C.

Appendix C. Worksheet for determining noise level and radiation dose in small-, medium-, and large-sized patients

			□ Small	□ Medium	□ Large
	Chest Width	Tube Current	Image Noise	DLP	Effective dose
Patient 1					
Patient 2					
Patient 3					
Patient 4					
Patient 5					
Patient 6					
Patient 7					
Patient 8					
Patient 9					
Patient 10					
Patient 11					
Patient 12					
Patient 13					
Patient 14					
Patient 15					
Average					

Appendix D. Calculation of E on the basis of DLP

A simple method for obtaining a reasonable approximation of the effective dose was proposed by the European Working Group for Guidelines on Quality Criteria in Computed Tomography. This method groups tissues into body regions and assigns a single coefficient to each region on the basis of the radiosensitivities of all tissues within the region.[25] The effective dose, E, for cardiovascular imaging can then be estimated as $E = DLP \times k$, where k is the coefficient for the chest. Most estimates of effective dose to date derived with the use of this equation are based on $k = 0.017 \text{ mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$ as originally proposed by the European Commission.[25] However, a more recent publication by the same group recommends using $k = 0.014 \text{ mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$.[26] The use of this newer value has subsequently been endorsed by the American Association of Physicists in Medicine (AAPM)[27] and the National Radiological Protection Board (NRPB). Historical data that were based on the older, higher k value must then be adjusted before comparison to new data on the basis of $k = 0.014 \text{ mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$.