

## Guidelines

# SCCT guidelines for performance of coronary computed tomographic angiography: A report of the Society of Cardiovascular Computed Tomography Guidelines Committee

Suhny Abbara, MD, Armin Arbab-Zadeh, MD, Tracy Q. Callister, MD, Milind Y. Desai, MD, Wilfred Mamuya, MD, PhD, Louise Thomson, MBChB, FRACP  
Wm. Guy Weigold, MD\*

*Society of Cardiovascular Computed Tomography, Washington, DC 20037, USA*

### KEYWORDS:

Cardiovascular computed tomography;  
Computed tomography;  
Coronary angiography;  
Coronary artery disease;  
Guidelines;  
Spiral computed tomography;  
X-ray computed tomography

## Preamble

The increasing use of coronary computed tomographic angiographic (CTA) requires the establishment of standards meant to ensure reliable practice methods and quality outcomes. The Society of Cardiovascular Computed

Tomography Guidelines Committee was formed to develop recommendations for acquiring, interpreting, and reporting of these studies in a standardized fashion. Indications and contraindications for specific services or procedures are not included in the scope of these documents. These recommendations were produced as an educational tool for practitioners to improve the diagnostic care of patients, in the interest of developing systematic standards of practice for coronary CTA based on the best available data. Because of the highly variable nature of individual medical cases, an approach to interpretation or reporting that differs from these guidelines may represent an appropriate variation based on a legitimate assessment of an individual patient's needs.

**Conflict of interest:** The authors report no conflicts of interest.

The Guidelines Committee consisted of Gilbert L. Raff, MD (Co-Chair), Wm. Guy Weigold, MD (Co-Chair), J. Jeffrey Carr, MD, Mario J. Garcia, MD, Jeffrey C. Hellinger, MD, and Michael Poon, MD.

\* Corresponding author.

E-mail address: [guy.weigold@medstar.net](mailto:guy.weigold@medstar.net)

Submitted March 19, 2009. Accepted for publication March 24, 2009.

The Society of Cardiovascular Computed Tomography Guidelines Committee makes every effort to avoid any actual or potential conflicts of interest that might arise as a result of an outside relationship or a personal interest of a member of the Guidelines Committee or either of its Writing Groups. Specifically, all members of the Guidelines Committee and of both Writing Groups are asked to provide disclosure statements of all such relationships that might be perceived as real or potential conflicts of interest relevant to the document topic. The relationships with industry information for Committee and Writing Group members are published in the appendices of the document. These are reviewed by the Guidelines Committee and will be updated as changes occur.

## 1. Introduction

The rapid technologic development of multidetector row computed tomography (MDCT) over the past decade has significantly increased our ability to image the heart and coronary arteries noninvasively. Multiple studies have shown that coronary artery stenoses can be identified with high sensitivity and specificity by coronary CT angiography if image quality is adequate. An expert consensus document has defined a number of clinically “appropriate,” “inappropriate,” and “uncertain” indications for coronary CTA.<sup>1</sup>

It is generally accepted that the diagnostic quality of coronary CTA is highly dependent on a number of technical factors, including hardware, software, and acquisition protocols. These factors continue to evolve at a rapid pace, resulting in the “state of the art” being in a continuous “state of flux.” Several MDCT scanner types are currently utilized for coronary CTA and provide a wide array of options. These include a range of 16–320 detector systems, single- or dual-source scanners, a variety of 3D workstations for processing and reviewing the scan data, and a large number of software programs with multiple functionalities. Furthermore, there are also numerous ways of acquiring, processing, and reviewing coronary CTA data.

Therefore, this publication aims to establish a consensus of the minimally required standards for appropriate coronary CT angiography acquisition and data processing and to provide recommendations for methods to optimize scan results, maximize image quality, and avoid unnecessarily high radiation exposure.

## 2. Physician and technologist competencies; Institution and scanner standards

### 2.1. Physician standards

All examinations should be performed and interpreted by physicians adequately trained in cardiac CT. This also includes adequate knowledge of the ALARA (As Low As

Reasonably Achievable) principle from the standpoint of radiation exposure, and the ability to assess coronary arteries, cardiac and pericardial structures, great vessels, and extra-cardiac structures. Interpreting physicians should have adequate training as described in competency statements issued by medical specialty societies (eg, the ACC/AHA Clinical Competence Statement on Cardiac Imaging with Computed Tomography and Magnetic Resonance,<sup>2</sup> or the ACR Practice Guideline for the Performance and Interpretation of Cardiac Computed Tomography<sup>3</sup>). An imaging center should have a supervising physician with advanced knowledge in cardiovascular CT and radiation issues. Certification of advanced expertise in cardiac CT is desirable (eg, diplomate of the Certification Board of Cardiovascular CT [CBCCT] or holder of the ACR Certificate of Proficiency in Cardiac CT).

### 2.2. Technologist and ancillary personnel standards

All examinations should be performed by technologists adequately trained in cardiac MDCT. This also includes adequate knowledge of the ALARA principle from the standpoint of radiation exposure. Moreover, technologists should receive additional training to perform cardiac CT on their respective equipment, including scanner and injection devices.

At least one person with appropriate training in inserting intravenous access (peripheral IV) is required for patient preparation, and at least one person certified in advanced cardiac life support has to be readily available during the acquisition. If additional medications are used, a person with adequate training in administering medications such as  $\beta$ -blockers and nitroglycerin must be available. The above functions could be performed by a physician or physician assistant.

### 2.3. Institution and equipment standards

The imaging facility should meet laboratory accreditation standards as set forth by the applicable body, eg, the Intersocietal Commission for the Accreditation of Computed Tomography Laboratories (ICACTL), or the American College of Radiology (ACR). Scanners with gantry rotation times of 420 milliseconds or less should be utilized for coronary CTA, although less than 400-millisecond gantry rotation time is recommended. The minimum detector requirement is a 16-slice scanner; however, systems with at least 32 detector rows or more are recommended (collimations of  $32 \times 2$  or  $64 \times 1$ , or newer generation). The detector element width should be no more than 0.75 mm. At a minimum single-head power injectors that allow fast injection rates (4–7 mL/s) are required; however, dual-head injection pumps that allow biphasic or triphasic injection protocols are recommended. For a detailed description of the different injection protocols, please refer to Section 5. A CT data archiving system is required to allow storage and retrieval of the entire diagnostic image data set.

## 2.4. Radiation monitoring standards

Independent of local policy and legislation, it is recommended that the radiation dose estimates from each coronary CTA, as calculated by the scanner after acquisition, should be recorded for each patient. Dose-length product (in mGy · cm) should be used; effective dose (in mSv) may be recorded in addition; however, the conversion factor for calculating effective dose may change over time, giving discrepant results. The radiation doses need to be stored in a format that allows for retrieval and periodic review of representative samples of the data. Examples of formats for recording include, but are not limited to, a Digital Imaging and Communications in Medicine (DICOM) image with radiation information in a picture archiving and communication system (PACS), a paper-based logbook, hospital information system (HIS) or radiology information system (RIS), or a dedicated database or local registry. It is imperative that the laboratory director, or equivalent physician, ensures (1) the presence of and adherence to a periodic (eg, biannual) review of the range of radiation doses, and the median and average radiation dose at the site and (2) comparison of the local data with national standards and other published references. This review process should trigger the review and optimization of scanning protocols, especially if the site radiation dose is higher than comparable national or international references.

## Recommendations

- The supervising physician (laboratory director, etc) should have advanced knowledge and expertise in cardiovascular CT and medical radiation. Certification of advanced expertise in cardiac CT is desirable.
- The interpreting physician should have adequate training as described in competency statements.
- Technologists should be adequately trained to perform cardiac CT on the respective equipment, including scanner and injection pumps.
- The institution should meet or exceed current standards for medical imaging facilities.
- The scanner should meet or exceed current standards.
- Radiation dose estimates from coronary CTA should be recorded for all patients.
- Periodic review of the site's radiation levels and comparison with published references (and internal protocol review and optimization) is necessary and should be performed at least twice per year.

## 3. Patient screening and preparation

### 3.1. Introduction

The decision to order a cardiac CT should be made by a qualified physician or under supervision of a qualified

physician following current national guidelines. Cardiac CT should only be performed if the results of the test have the potential to affect patient management or prognosis.

Patient preparation should be performed by a qualified person. Patients should be screened for contraindications to contrast-enhanced CT in general or for factors that may interfere with image quality in coronary CTA. Blood pressure and heart rate before administration of  $\beta$ -blocker and/or nitroglycerin should be noted. Blood oxygen saturation monitoring may be required in critically ill patients for whom CT imaging is contemplated. The following is a description of standard procedures that need to be performed before a coronary CTA.

### 3.2. Initial screening

Cardiac CT is generally contraindicated in the following clinical scenarios; however, on a case-by-case basis, cardiac CT may be pursued in some of these scenarios if clinically warranted.

Contraindications to cardiac CT include a known history of severe and/or anaphylactic contrast reaction, inability to cooperate with scan acquisition and/or breath-hold instructions; pregnancy, clinical instability (eg, acute myocardial infarction, decompensated heart failure, severe hypotension, etc), and renal insufficiency. Regarding pregnancy in particular, a chest CT results in low radiation exposure to the fetus; however, a negative long-term effect even from low level radiation cannot be excluded.<sup>4</sup> Furthermore, small amounts of absorbed iodine from the contrast material may affect the fetus' thyroid function.<sup>5</sup> Although coronary CTA in pregnant women may not be absolutely contraindicated, the indication should be critically reviewed. As with every procedure, alternative imaging modalities should be considered, and the study with the best benefit–risk ratio should be used. Women of childbearing age should undergo a pregnancy test before being considered for coronary CTA. For breastfeeding mothers it is reassuring to note that iodine accumulation in the breast milk is considered too low to warrant interruption of their breastfeeding schedule.<sup>5</sup>

In addition to these contraindications, there are also a number of patient-related variables that affect the diagnostic accuracy of coronary CTA. The presence of such factors should trigger reconsideration of the risks and benefits of the procedure with the decreased accuracy in mind. These variables include obesity; difficulty following breath-hold commands, maintaining body position, raising the arms, or lying supine for scanning; contraindication to  $\beta$ -blockade in the presence of an elevated heart rate; heart rate variability and arrhythmia; and contraindication to nitroglycerin. Regarding obesity in particular, scan restrictions for upper weight limits depend on the scanner dimensions and characteristics. Many scanners are approved to scan patients of up to 450 pounds body weight or more. However, image quality for coronary assessment in such patients may be inadequate even

with maximum scanner output. It is the attending physician's responsibility to consider the scanner's characteristics appropriately for the probability of imaging success.

With these considerations in mind, pre-procedural screening should therefore include the following. Some elements of this screening process can take place during the initial test scheduling, while others are more appropriately executed on arrival at the imaging center.

1. History taking to evaluate for:
  - a. Pregnancy or potential pregnancy: According to ACR recommendations "All imaging facilities should have policies and procedures to identify pregnant patients prior to imaging, and to consider any possible risks to the fetus of any planned administration of contrast material, taking into consideration the potential clinical benefits of the examination."<sup>3</sup>
  - b. Contraindication to contrast media or other medications including  $\beta$ -blockers and nitroglycerin
  - c. Renal insufficiency and risk of contrast-induced nephrotoxicity (CIN)
  - d. Prior allergic reactions to any allergens
  - e. Active bronchospastic disease, hypertrophic cardiomyopathy, severe aortic valve stenosis, or other precautions or contraindications to  $\beta$ -blockers
  - f. Current medications (especially sildenafil, vardenafil, tadalafil, or metformin)
  - g. Any other pertinent medical history
2. Assessment of the ability to follow breath-hold commands and perform inspiratory breath-hold
3. Assessment of body weight
4. Assessment of heart rate (preferably after inspiration) and arrhythmia
5. Assessment of blood pressure

### 3.3. Pretest instructions

Patient instructions are best given when the procedure is scheduled. The following is a list of the typical set of instructions:

1. No food for 3–4 hours before examination.
2. May drink water or clear fluids up until time of examination (patient should be well hydrated for renal protection, for ease of establishing venous access, and to avoid postprocedure hypotension).
3. No caffeine products for 12 hours before examination, because they might hinder efforts to reduce the heart rate before scanning. This includes coffee, tea, energy drinks, energy pills, diet pills and most soda.
4. Take all regular medications the day of examination, especially blood pressure medicine.
5. Take pre-medications for contrast allergy as prescribed by the ordering physician. As an example, the standard Greenberger regimen is prednisone, 50 mg by mouth,

13, 7, and 1 hour before contrast exposure, in addition to diphenhydramine 50 mg by mouth 1 hour before contrast exposure.<sup>6</sup>

6. Metformin use must be discontinued for at least 48 hours after the contrast administration. Metformin itself is not nephrotoxic, but it is exclusively renally cleared. If renal failure is precipitated by iodinated contrast, a toxic accumulation of metformin may result, which can induce lactic acidosis. There is no evidence that withholding metformin *before* a contrast procedure is protective, although this approach has been adopted by some.

### 3.4. Informed consent

Whether or not informed consent before performance of coronary CTA should be required may be regulated by institutional, regional, or state regulations. A consent form, if used, should explain in simple terms the procedure and the reasonably expectable risk to the patient.

### 3.5. Intravenous access

Intravascular access should be established using the facility's protocol, and adequate flow should be ascertained before injection. Cannula size and position should be adequate for the high flow rate of power injector bolus intravenous administration of contrast and in accordance with the individual facility policy. A short 20-gauge intravenous catheter may be sufficient in normal or small patients, but an 18-gauge intravenous catheter may be necessary for more rapid infusion rates (larger patients). The right antecubital vein is preferable (median, cubital, basilic, and cephalic veins), followed by a left antecubital vein. Hand veins (metacarpal and dorsal) should be avoided, unless no other suitable access can be established. This generally requires a 20-gauge or smaller catheter and slower flow rates. Unless specifically labeled for power injection, central lines should not be used.

### 3.6. Renal precautions

Pretest determination of estimated glomerular filtration rate (GFR) is not required for all patients, but it should be performed for patients considered at increased likelihood of renal impairment on the basis of age and history, because impaired renal function is a relative contraindication to coronary CTA. Calculation of GFR, rather than creatinine alone, is encouraged.<sup>7,8</sup> The incidence of contrast-induced nephropathy (CIN) increases in patients with impaired kidney function (estimated GFR < 60 mL/min/m<sup>2</sup>) and other comorbidities such as cardiomyopathy (left ventricular ejection fraction < 40%) and diabetes mellitus. The risk is higher in the elderly as well as in patients with a small body mass index (BMI). Patients who are dehydrated or volume depleted before contrast exposure have an

increased risk, and any condition that decreases renal blood flow (hypotension, nonsteroidal anti-inflammatory use) is also likely to increase risk of CIN. There is substantial literature examining the prevention of contrast nephropathy in populations with cardiovascular disease undergoing invasive coronary angiography or peripheral angiography with direct arterial intravascular injection of contrast.<sup>9–12</sup> It is unclear if this literature can be extrapolated to approaches for prevention of contrast nephropathy in the setting of peripheral venous administration of contrast CT. One MDCT study of 166 patients with renal insufficiency reported CIN rates between 2.6% and 4%,<sup>13</sup> and in a study of 400 patients with renal insufficiency undergoing MDCT and receiving CIN-preventive measures, the incidence of CIN was < 2%.<sup>14</sup>

Risks and benefits of contrast administration in patients with impaired renal function must be carefully considered. If contrast is to be injected, it is recommended to follow local protocols for prescan hydration (which may need to be modified to avoid volume overload in patients with reduced left ventricular function).<sup>15</sup> The use of N-acetylcysteine or bicarbonate may be considered, but available data are not sufficient to make recommendations.<sup>16–19</sup>

### 3.7. Preprocedure medications and instructions

#### 3.7.1. $\beta$ -Blockade

Most current generation MDCT scanners require both a slow heart rate and a regular cardiac rhythm for optimal image quality.<sup>20–22</sup> The requirement for heart rate reduction varies depending on the scanner temporal resolution and the indication for imaging. Image quality is generally better if the heart rate is less than 60 beats/min during the scan.  $\beta$ -Blockers are generally used to achieve short-term heart rate reduction for the purpose of coronary CTA, and protocols may use oral, intravenous, or both routes of drug administration. The administration of oral and intravenous  $\beta$ -blockers requires compliance with institutional policies. Metoprolol has become the standard because of demonstrated safety in patients with congestive heart failure and significant chronic obstructive pulmonary disease, and because of its low cost and reliability.<sup>23</sup> Atenolol may be chosen in patients with significant hepatic dysfunction because of its renal route of clearance. The most common oral approach uses a total of 100 mg of metoprolol. Hence, one possible protocol is to give 100 mg by mouth 1 hour before the scan (slow-release forms should not be used) or to give 50 mg by mouth 12 hours before the scan and another 50 mg by mouth 1 hour before imaging. If the heart rate remains above 60 beats/min, additional metoprolol may be given intravenously to expedite further heart rate reduction.

Alternatively, an intravenous approach can be used to shorten the overall time required for preparation. After the patient is placed on a cardiac monitor, 5 mg of intravenous

metoprolol is given as an initial dose, followed by 5 minutes of monitoring to observe the heart rate response. Further intravenous doses of 5 mg may be administered as indicated to achieve the desired heart rate. Patients with active bronchospastic diseases should, in general, not receive  $\beta$ -blockers, and, in those patients, the use of alternative drugs such as short-acting calcium channel blockers or ivabradine may be considered, although no data as to their efficacy are currently available. Caution is advised in the use of  $\beta$ -blockers in the setting of known or suspected sick sinus syndrome, unexplained presyncope or collapse, current use of other antiarrhythmic medications (including but not limited to calcium channel blockers, digoxin, or amiodarone), depressed left or right ventricular function, a history of bronchospastic disease, or allergy to  $\beta$ -blockers.

A 12-lead electrocardiogram (ECG) before administration of  $\beta$ -blockers and cardiac monitoring during the study should be considered, depending on the degree of patient risk.

#### 3.7.2. Nitrates

In the absence of contraindications, nitrates should be administered before coronary CTA to achieve coronary vasodilatation and to improve image quality.<sup>24,25</sup> A commonly used regimen is 400–800  $\mu$ g (1–2 tablets, and preferably the latter) of sublingual nitroglycerin a few minutes before the initiation of the scan protocol. Nitrates may reduce the blood pressure, but they are considered safe in the supine position, providing there is not hypotension before the procedure.

Use of nitroglycerin is contraindicated if the patient has recently taken erectile dysfunction medication (eg, sildenafil, vardenafil, or tadalafil) or is taking sildenafil for pulmonary hypertension. Use is also contraindicated in those clinical states in which systemic vasodilation may result in deleterious consequences of transient decrease in systemic blood pressure. These include pronounced hypovolemia, inferior wall myocardial infarction with right ventricular involvement, raised intracranial pressure, cardiac tamponade, constrictive pericarditis, severe aortic stenosis, hypertrophic obstructive cardiomyopathy, and severe systolic hypotension.

#### 3.7.3. Breath-hold training

It is essential to minimize patient motion, even respiratory motion, during image acquisition. Before initiating the actual scan, explicit instructions and practice regarding breath-holding need to be given in the form of test breath-holding. The purpose of the practice is to observe for problems with the heart rate and rhythm, to ensure the technique the patient is using is correct (no Valsalva), and to ensure that the patient clearly understands the breath-holding instructions. If adherence to breath-hold commands is obviously inadequate, the scan should not be performed.

It is strongly advised that all steps of the scan protocol (topogram, calcium score, and test bolus, if performed, as

well as the coronary CTA acquisition) are performed with exactly the same breath-hold commands.

### Recommendations

- The decision to order a cardiac CT should be made by a qualified physician or under supervision of a qualified physician following current national guidelines.
- Coronary CTA should only be performed if the results of the test have the potential to affect patient management or prognosis.
- Initial screening should take place for contraindications to coronary CTA and for factors that may reduce its diagnostic accuracy.
- Coronary CTA should not be performed in the presence of contraindications (eg,  $\text{GFR} < 60\text{mL}/\text{min}/\text{m}^2$ ), unless careful deliberation demonstrates that the risks from the test are outweighed by the potential benefit and the risk from not performing the test.
- In situations that increase the likelihood of non-diagnostic image quality, the relative merits of coronary CTA should be judged against the risks of additional radiation and nephrotoxicity.
- Intravenous access should be adequate for high flow and high pressure contrast injection.
- Glomerular filtration rate (GFR) should be determined for patients at increased likelihood of renal impairment.
- $\beta$ -Blocker use should be considered based on its requirement as indicated by scanner and patient factors and the indication for imaging. Patient factors permitting, the heart rate during scanning for coronary CTA should be less than 65 beats/min, and ideally less than 60 beats/min.
- A 12-lead ECG and cardiac monitoring should be considered if  $\beta$ -blockers are used, depending on the degree of patient risk.
- In the absence of contraindications, nitroglycerin should be used to enhance coronary visualization.
- Explicit breath-holding instructions and breath-hold training must be provided before scanning.

## 4. Patient positioning

Proper patient positioning and ECG lead placement are important to ensure adequate image quality in a cardiac CT acquisition. The major objectives for positioning of the patients are (1) to minimize the presence of extraneous high-density material (eg, ECG leads) within the scan field (ie, lower two-thirds of the chest) that may produce streak artifacts and (2) to position the heart within the center of the gantry by adjusting the table height and lateral position of the patient on the scan table.

If possible, patients should be imaged supine and with both arms above the head. This removes the humeri from the field of view (FOV) and reduces streak artifact and

image noise. The arms should be positioned comfortably to avoid pectoral fatigue or trembling that can lead to ECG irregularities and gating errors. Care should be taken to keep the arm with the intravenous access as straight as possible to avoid line or vein kinking and to facilitate contrast agent injection. The contrast pump and intravenous line should approach the patient from the cranial side so that the line does not cross through the gantry, which would produce streak artifact.

The table height should be adjusted for each patient to center the heart within the gantry to optimize spatial and temporal resolution.<sup>26,27</sup> The horizontal positioning laser lights can be used for this purpose: when correctly positioned, the laser line lies at the junction of the anterior one-third and the middle one-third of the patient's thorax.<sup>28</sup> It is reasonable to offset patients laterally by a few centimeters to center the heart within the gantry, as long as this does not impede table motion or result in contact between the patient and gantry during the acquisition. It is recommended to move the patient through the gantry for the expected respective scan range (ie, a "test run") to ensure that no lines or leads are tethered and that the patient does not contact the gantry. Contact of the patient with the gantry may result in passive or active (protective) body motion, producing artifacts that may not be correctable through postprocessing. The scanner's ECG leads should be straightened and care taken that the leads do not unnecessarily traverse the scan range to avoid streak artifact and image noise. Likewise, any other leads, metal, or radio-opaque material should be removed (inferiorly onto the abdomen, or superiorly) from the scan field.

To obtain a reliable ECG tracing, proper placement of ECG leads is critical. The number and preferred location of leads depends on the scanner type and design. Care should be taken to place leads outside the imaging FOV to the extent possible to avoid streak artifact. Cleaning the skin with alcohol and shaving at the site of electrode placement may be necessary to ensure sufficient electrode-to-skin contact. For best recognition of ECG trigger points, it is important to obtain a steep upslope toward the R peak and sufficient R-peak voltage with minimal baseline noise. Replacement of ECG leads is necessary if the baseline noise is relatively high compared with the R-peak amplitude, or if the amplitude of the T wave is in a similar range as that of the R peak because this may result in false triggering (R-peak detection).

### Recommendations

- The preferred patient position is supine with arms raised above the head and the heart centered within the gantry.
- Special attention should be paid to ensure proper positioning and firm contact of the ECG leads to ensure a high R-peak amplitude and low baseline noise.

## 5. Contrast injection protocols

### 5.1. Contrast type, delivery, volume, and rate

Image quality is dependent on the contrast-to-noise ratio. Optimal images require high intraarterial opacification of more than 250 Hounsfield units (HU). Hence, contrast agents with high iodine concentrations are preferred. The required injection rate is typically between 4 and 7 mL/s. Warming of contrast agent improves viscosity and allows higher injection rates at lower injection pressures. The overall contrast volume is a function of the injection rate and the injection duration. The injection duration should be as long as or slightly longer than the estimated scan duration. For very short scans, the injection duration should be at least 10 seconds. In patients with higher cardiac output, the injection rate should be increased to allow the arterial opacification to remain high. Typical contrast volumes range from 50 to 120 mL. Although single-head pumps allow for adequate image quality studies, dual-head pumps have the advantage of allowing contrast injection to be followed by saline injection, or in some cases to be followed by a mixture of contrast and saline.<sup>29–32</sup> A biphasic injection protocol consists of a first injection of contrast at a rate of 4–7 mL (volume depends on scan length) and a second injection of approximately 40–50 mL of saline, typically at the same injection rate. In these protocols the right heart typically appears washed out, which in some instances may be desired. In some clinical settings it may be desirable to have some opacification of the right heart. In such cases the saline flush may be replaced by a mixture of contrast and saline, or a triphasic injection protocol may be used. Triphasic protocols consist of an initial high flow rate contrast injection (4–7 mL/s), followed by a second injection of either a mixture of contrast and saline (4–7 mL/s), or a contrast injection at lower injection rate (eg, 2 mL/sec), followed by a third injection of a smaller volume of saline.

### 5.2. Test bolus versus bolus tracking

Accurate timing of the scan to the arrival of the IV contrast in the target structures is necessary. Vascular enhancement should be maintained for the duration of data acquisition. Because overall scan durations are short in coronary CTA (2–30 seconds), timing errors of even 5–10 seconds can make a substantial difference. Normally, the scan delay should equal the contrast travel time from the accessed vein to the ascending aorta plus 2–3 seconds to allow complete filling of the coronary arteries. Three strategies are available to determine the vein-to-aorta travel time (“delay time”).

The easiest but least reliable is a fixed “best guess” of 22–25 seconds. Because of the high risk of a mistimed bolus resulting in a non-diagnostic study, this approach is not recommended. One of the two acceptable strategies (“bolus tracking”) is automatic scan triggering. A region of interest is selected over the ascending or descending aorta and is sampled approximately every 2 seconds after the initiation of the contrast bolus. When the density in the region of interest rises

to a preset value (eg, 100 HU), the system will automatically play a short, prerecorded breath-hold instruction to the patient, and the scan will automatically commence.

The other acceptable strategy (“test bolus”) requires a small test bolus injection (typically 10–20 mL of contrast followed by a saline bolus of approximately 50 mL, both injected at a rate of 4–7 mL/s) and, in inspiratory breath-hold, sampling at the level of the ascending aorta every 1–2 seconds. In this way, the delay time can be accurately measured. This strategy offers several advantages: decreased risk of false starts or delays, identification of contrast dilution problems, ensuring adequacy of the intravenous line, and a chance to observe the patient before the real scan.

### 5.3. Contrast reaction protocols

The CT laboratory has to be equipped and staffed appropriately for handling the rare event of anaphylaxis.<sup>33</sup> Immediate treatment by appropriately trained personnel is necessary in case of anaphylaxis. ACR or ACC guidelines for management of contrast reactions should be followed in the appropriate settings.<sup>34</sup>

## Recommendations

- High iodine concentration contrast agents are preferred to achieve greater contrast-to-noise ratios.
- Intravenous contrast injection rates of 4–7 mL/s should be used.
- Total contrast volume should be based on injection rate and scan duration and is typically 50–120 mL.
- Dual-head power injectors are preferred over single-head injectors.
- Biphasic or triphasic injection protocols should be used.
- Either bolus tracking or a test bolus protocol is acceptable. Timed scans (using timing alone without either bolus tracking or a test bolus) are not recommended.
- The CT laboratory should be appropriately equipped and staffed to manage contrast reactions, including anaphylaxis.

## 6. Coronary CTA acquisition

### 6.1. Overview of X-ray radiation

X-ray radiation has the potential to cause harm. It is critically important for any physician ordering or applying x-rays to have a fundamental understanding of the risks from radiation and of the measures to minimize exposure to patients.

The average annual radiation exposure arising from natural sources (radon, cosmic radiation, terrestrial, etc) for a person living in the United States accounts for an effective radiation dose of approximately 3 mSv. In addition, radiation exposure from medical sources has increased substantially in

the past decade. CT scanning is responsible for a large part of this increase.<sup>35</sup> The main concern about exposure to ionizing radiation is the potential induction of cancer. Radiation may cause DNA damage, which the cell usually repairs. However, with repeated damage and repair the chances of malignant mutations increase.<sup>36</sup> Although there are limited direct data available for the estimated risk from low-level radiation, most experts assume that there is a direct linear relationship between the amount of radiation received and the risk of cancer.<sup>37</sup> Furthermore, it is assumed that there is no safe amount of radiation and that any radiation exposure is potentially harmful.<sup>38</sup> Available data suggest that particularly children and young adults are at risk from radiation exposure.<sup>39</sup> The harmful effect is cumulative, ie, the more radiation exposure one experiences in life, the greater the risk. In addition, there is long latency (>10–30 years) before the manifestation of cancer, which will affect children, but may not be relevant in older adults. Finally, growing tissue and organs may be more susceptible to genetic damage induced by radiation than tissue with low turnover.

Radiation exposure to the patient from coronary CTA varies substantially with the image acquisition protocol and settings and type of scanner used. Effective radiation dose from 64-slice retrospectively ECG-gated coronary CTA typically ranges from 8 to 25 mSv.<sup>40</sup> Because of higher sensitivity of breast tissue to radiation, radiation risks of coronary CTA are higher for women than for men.<sup>41</sup>

For these reasons, it is imperative to assure for every patient that CT scanning is indeed indicated and that all possible actions are being undertaken to minimize radiation exposure to the patient, in accord with the ALARA principle.

Because more radiation generally results in better tissue penetration and image quality, the benefits of acquiring images of diagnostic quality have to be weighed against the risks of radiation for each individual patient. Accordingly, for each patient the degree of image quality required should be determined before scan acquisition to adjust the scan technique and deliver the minimum required radiation exposure. For example, a coronary CTA to delineate the course of a coronary anomaly might be performed with less radiation exposure than a standard coronary CTA because the course of a vessel can be determined from images of lower resolution than that required for stenosis quantification. Likewise, if scanning only for left atrial and pulmonary vein anatomy before an ablative procedure when knowledge of the coronary artery anatomy is not needed, the scan can and should be performed with a low radiation exposure protocol (eg, by increasing slice thickness). With the strategies outlined below to keep radiation dose to a minimum, effective radiation dose (derived from the dose-length product [DLP]) for the contrast-enhanced portion of a standard scan length (ie, half-chest) coronary CTA typically does not exceed 20 mSv. Thus, every effort should be undertaken to keep radiation dose lower than this limit while

maintaining adequate image quality. Many laboratories report excellent results with average doses of less than 10 mSv using current technology.<sup>42</sup>

## 6.2. Techniques to reduce radiation

### 6.2.1. General principles

Factors influencing the overall radiation exposure include the scanner type (multidetector, dual source, gantry rotation, filters, scanner geometry, etc), tube voltage, tube current, scan range, scan acquisition time, gating (prospective versus retrospective), slice thickness, overlap and pitch (for helical scanning), and scatter. All factors need to be taken into consideration for minimizing radiation exposure as much as reasonably possible.

### 6.2.2. Tube voltage

Typically, 100–120 kV tube voltage is sufficient for cardiac imaging in most patients. Increasing tube voltage to 140 kV leads to a higher energy x-ray beam with better tissue penetration, resulting in a reduction of image noise, but also in substantially higher radiation exposure. In fact, the dose change is approximately proportional to the square of the tube voltage change.<sup>43</sup> For some extremely large patients, an increase in tube voltage to 140 kV may be necessary to achieve acceptable noise levels, but this should be a rare exception. However, in smaller patients and children, reduction of the tube voltage to 100 or 80 kV will save 30%–50% radiation, while maintaining adequate contrast-to-noise ratio.<sup>44,45</sup> Reducing voltage from 120 kV to 100 kV should be considered when the patient's weight is below 85 kg and the BMI is below 30 kg/m<sup>2</sup>.

### 6.2.3. Tube current

More commonly, the tube current is modified to adjust for patient size/weight and desired image noise. Increase in tube current results in more photons per exposure time, leading to less image noise, but greater radiation exposure. In contrast to the tube voltage, the increase in radiation dose is approximately proportional to the change in tube current. In general, larger patients need greater tube current to reduce image noise (generated by more tissue penetration) to an acceptable level. It has to be emphasized again that tube current should only be increased to a level necessary for acquiring images of adequate quality.

### 6.2.4. Automatic exposure control

Although the tube current should be adjusted for each patient according to the patient's size and scan indication, many scanners have additional features that can lower the tube current during the image acquisition, called "tube current modulation." One form of tube modulation, also called "automatic exposure control," lowers the tube current when the x-ray beam is penetrating less dense tissue (ie, lungs) and increases the current when more solid tissue is penetrated. This form of tube modulation, however, is not

very effective in dose reduction for cardiac imaging, probably because of the relative uniform distribution of tissue densities in the typical scan range for cardiac CT.<sup>46</sup>

### 6.2.5. ECG-based tube current modulation

A more effective form of dose reduction in retrospectively ECG-gated coronary CTA is ECG-based tube current modulation. This concept considers the fact that coronary motion is least during limited phases of the cardiac cycle (end systole and end diastole) and that image reconstruction during other cardiac phases frequently results in motion artifacts, thus generating images which are not useful for interpretation. Accordingly, tube current is reduced during the cardiac cycle when coronary motion is likely greater (most part of systole) and ramped up during diastole when coronary motion is least. Dose savings up to 50% can be obtained using ECG-based tube current modulation depending on the protocol and scanner used.<sup>44</sup> The downside is reduced image quality (more noise) during those phases of the cardiac cycle with lower tube current: images reconstructed from reduced-current phases are objectionably noisy. This does not usually hinder cardiac function analysis because the ventricular contours can still be visualized, but it usually limits the interpretation of coronary arteries in the reduced-current phases. If ECG-based tube current modulation is used properly in selected patients (ie, regular sinus rhythm, low heart rates), it will result in diagnostic images in almost all cases while achieving substantial savings in radiation exposure.<sup>44</sup> Improved algorithms for ECG-based tube current modulation continue to further reduce limitations for higher or irregular heart rates. ECG-based tube current modulation, therefore, should routinely be used in every patient and only deactivated, with particular consideration of the risk–benefit ratio, in selected patients when full image quality throughout the cardiac cycle is absolutely necessary or in patients with irregular heart rates that make ECG-based dose modulation unreliable. It is worth mentioning that the dose reduction effects of this method are largest in patients with low heart rates in whom very short windows of full radiation exposure can be used, and the relative duration of the window of full radiation is therefore shorter compared with higher heart rates. Thus, routine lowering of the heart rate for coronary CTA in conjunction with ECG-based tube current modulation substantially contributes to radiation dose saving

### 6.2.6. Scan range

The greater the scan range, the greater the radiation exposure. Therefore, the scan range should be limited to the extent that is necessary to address the question posed. For example, if not specifically requested or otherwise indicated, a cardiac scan for assessment of the native coronary arteries should focus on a scan range sufficient to include the heart and not include other areas, such as the aortic arch. Obtaining a low-dose scan to determine the smallest required scan field to minimize radiation dose is not recommended, because it does

add radiation and utilization of anatomic landmarks is generally sufficient. The scan range for coronary CTA typically starts at the tracheal bifurcation or the mid-level of the left pulmonary artery and extends to just below the lower cardiac border.

### 6.2.7. Cardiac gating

Of particular importance for radiation exposure is the decision to use prospective ECG triggering or retrospective ECG gating.<sup>47</sup> In retrospective ECG gating, x-ray data are acquired throughout the entire cardiac cycle, and only data acquired during the cardiac phase with the least motion are used for image reconstruction. In prospective triggering, the x-ray tube is activated only during a prespecified phase within the cardiac cycle. Similar to ECG-based dose modulation, x-ray data are obtained during the phase of the cardiac cycle with presumably the greatest likelihood of minimal coronary motion. Prospective triggering is commonly applied for coronary calcium scanning, and lately it is being used more frequently during routine coronary CTA. Because no x-ray data are acquired during the remainder of the cardiac cycle, savings in radiation dose compared with retrospective gating are substantial (up to 90%). The potential disadvantage of prospective triggering lies in the fact that images can be reconstructed only during the prespecified phase of the cardiac cycle, and no image reconstruction is possible outside this time window. In addition, no functional analysis is possible because images throughout the cardiac cycle are not available. If these images are of poor image quality, the entire study may be non-diagnostic. The window of full radiation can be as narrow as required to reconstruct one image (one-half of the gantry rotation time), but this leaves absolutely no flexibility to vary the time instant of image reconstruction. It is possible to widen the window of x-ray exposure, which allows adjustment of the time instant of image reconstruction and reduces the risk of non-diagnostic images but increases radiation exposure.<sup>42</sup> Preliminary experience with prospectively triggered coronary CTA suggests that diagnostic studies can be obtained with as little as 1–3 mSv.<sup>48,49</sup> Patients need to be carefully selected for prospective triggering. Currently, this technique is the most effective way of lowering radiation dose from cardiac CT and, therefore, should be strongly considered, depending on the MDCT scanner type, for patients who have a high radiation risk and in whom diagnostic image quality can be expected despite the limitations of prospective triggering (ie, a cooperative patient with a low and regular heart rate). Clinical expertise in heart rate and rhythm control on the part of the supervising physician will increase the likelihood that the benefits of prospective scanning capability will be realized in those patients who are candidates for this protocol.

### 6.2.8. Shielding

Intuitively, shielding of radiosensitive organs within (breast, lung) or outside (thyroid, intestine, gonads) the

scan field using lead- or bismuth-based protective material should help minimizing radiation exposure to the patient. However, studies performed with phantoms and patients suggest that shielding results in an increase of image noise and results in only modest reductions of radiation exposure for chest CT imaging.<sup>50</sup> Extrapolating from experience with chest CT, radiation exposure to organs outside the scan field during cardiac CT is negligible, not warranting shielding.<sup>51</sup> Until more conclusive data are available, shielding is not considered a routine tool to lower radiation exposure.

### 6.2.9. Other considerations

If helical scanning is used, slice thickness, slice overlap, pitch, and collimation influence radiation dose. Thinner slices generally increase radiation dose because of greater overlap/lower pitch, which increases acquisition time. With wider detector range and dynamic scanning, these factors are less relevant. Furthermore, the beam focus and scatter influence radiation dose, which, however, to a large extent are determined by the scanner characteristics. Scatter from patient's clothing, jewelry, and ECG leads, however, should be considered and avoided whenever possible.

Many CT laboratories use real-time tracking of the contrast arrival in the region of interest. The radiation exposure from this dynamic scanning of the region of interest before bolus arrival is fairly small but accumulates with prolonged scanning. It can be reduced by delaying the initiation of scan acquisition after the start of the contrast injection to the minimum travel time of contrast to the left heart injected in an arm vein (approximately 5–10 seconds).<sup>52</sup>

### 6.3. Monitoring radiation exposure

Current scanners display the estimated radiation exposure for each component of the scan as well as the total estimated dose for each study. The standard radiation dose parameter is the CT dose index (CTDI), which represents the estimated dose delivered to a CT phantom for given scan parameters (tube voltage, current, rotation time, etc). However, the CTDI does not account for the scan length and thus should not be taken as a surrogate for total delivered dose. The closest estimate to the actually delivered dose is the DLP, which takes into consideration a weighted CTDI (accounting for dose heterogeneity in the scan field), the scan length, and pitch/scan overlap. From the DLP, an estimation of effective radiation dose can be derived by weighting the DLP according to the region scanned, using a factor of 0.014 for the chest.<sup>53</sup> These values can be obtained during the planning stage of the scan (ie, after determining the scan range, heart rate during breath-hold) and should be considered for applying the least radiation to address the test indication. It is important to note however that the derived numbers are only rough estimates because they are based on phantom studies, and the anatomic assumptions are frequently not met in clinical practice. It is also important to note that radiation dose

estimates typically underestimate the true radiation dose, when actually measured.<sup>54</sup> Thus, the DLP should serve as a rough guide of estimated radiation dose delivered, and one should assume that the actual delivered doses exceed these estimates. The DLP is most useful to assess the relative dose reductions with alterations of the image acquisition, ie, change in tube voltage and current, implementing dose modulation etc, for optimized scan planning. It is therefore recommended to document DLP for every coronary CT angiogram and to institute periodic review of radiation exposure as outlined in Section 2.4.

## 6.4. Scan protocols

### 6.4.1. Overview image

Imaging starts typically with obtaining an anterior-posterior projection overview image (scout, topogram, topographic scout image, etc) that allows prescription of the scan range. The image position is the location of the axial slice relative to the position of the table and, therefore, relative to the position within the patient's chest, which in turn is relative to the "zero" position established when the patient is first positioned within the scanner. Generally the zero position for a chest CT is the suprasternal notch, just above the thoracic inlet, to perform a scout film that covers the entire chest, and scanning takes place in the cranial-to-caudal direction, with images reconstructed throughout the entire scanned length. In general, coronary CTA scans begin at the level of the tracheal bifurcation or main pulmonary arteries and end just below the diaphragm and are usually 12–15 cm in length.

### 6.4.2. Calcium score

Commonly, a scan for the detection of coronary calcification is performed as the next step for cardiac imaging. Images are most frequently obtained using prospective ECG triggering; ie, radiation exposure is confined to a predetermined phase within the cardiac cycle. This phase depends on the heart rate observed during the breath-hold test and typically ranges between 65% and 80% of the R-R cycle and occasionally at end systole. No contrast is given. The coronary calcium scan has two major advantages: (1) it helps to better define the smallest scan range to minimize radiation exposure, and (2) its result for the extent of coronary calcification may guide the next steps of the cardiac protocol.

### 6.4.3. Restrictions for high coronary calcium scores

Whether to proceed with a coronary CTA in the presence of extensive coronary calcification remains controversial. Vascular calcification leads to high levels of signal attenuation and can cause artifacts. Some studies have demonstrated that the greater the extent of coronary calcification, the greater the chance that coronary evaluation for lumen stenoses will be nondiagnostic in some segments.<sup>55,56</sup> At the same time, more extensive coronary calcification increases the likelihood that the patient has

obstructive coronary artery disease.<sup>57</sup> Accordingly, some centers do not proceed with a coronary CTA in the presence of a coronary calcium score exceeding 600–1000. However, such approaches have not been adequately studied nor validated. In selected patients, coronary CTA may yield useful information despite extensive coronary calcification, particularly in patients with low heart rates and a low-to-moderate body weight. Until more conclusive data are available, the decision to proceed with coronary CTA in the presence of a high coronary calcium score should be left to the discretion of the referring and attending physician.

#### 6.4.4. Coronary CT angiography

##### A. Heart rate considerations

The heart rate and its variability obtained during breath-hold are critically important for planning the scan. A low (ie, <60–65 beats/min) and regular heart rate may allow one to obtain images using prospective triggering or retrospective gating with ECG-based tube current modulation to save radiation dose to the patient (see Sections 6.2.7 and 6.2.5). Depending on the scanner type and software specifications, higher heart rates and irregular rhythms may require retrospective gating, potentially without ECG-based tube current modulation. Heart rates > 80 beats/min, particularly with irregular R-R intervals such as in atrial fibrillation, are used to represent a relative contraindication for coronary CTA because of high incidence of motion artifacts. However, ongoing hardware and software improvements, such as dual-source CT and wide-detector scanners, now allow the imaging of patients with higher and irregular heart rates with good imaging success.<sup>58,59</sup> Therefore, the limitations in regard to higher heart rates depend on the equipment used, and scan settings have to be adjusted accordingly. In general, the duration of systole remains relatively constant even with high heart rates. If prospective triggering is used, triggering exposure in end systole generally results in less motion artifacts. Premature atrial or ventricular complexes are often more troublesome because they may alter the R-R cycle abruptly without anticipation. Although there are software algorithms available, which recognize and adjust for arrhythmia, many scanners may still produce images with artifacts because of cardiac ectopy. The presence of frequent premature complexes before scanning therefore should trigger consideration of aborting the scan. Particularly, if radiation and contrast exposure are of concern, referral for cardiac catheterization may be justified.

##### B. Weight considerations

Scan settings should be adjusted to the patient's body weight. Both tube voltage and tube current should be optimized to deliver the least necessary radiation for adequate image quality (see Sections 6.2.2 and 6.2.3). In obese patients, higher tube current and tube voltage are required to

preserve contrast-to-noise ratio. The specific adjustments depend on the scanner specifications.

#### Recommendations

- Physicians operating MDCT must be intimately familiar with the concepts of risks from radiation exposure.
- Every effort must be undertaken to allow the lowest radiation exposure as reasonably achievable while maintaining diagnostic image quality.
- Tube voltage and current should be adjusted for each individual patient according to patient characteristics and test indication with the lowest settings necessary to achieve good image quality. When appropriate, use of 100 kVp is recommended to reduce radiation dose for patients with a BMI < 30kg/m<sup>2</sup>.
- The scan range should be as short as reasonably possible.
- ECG-based tube current modulation should be implemented in every patient if retrospective gating is used and if images of diagnostic quality to address the question posed are likely to be obtained.
- Prospective ECG triggering should strongly be considered in patients who have a high radiation risk and in whom diagnostic image quality can be expected (cooperative patient with a low and regular heart rate).
- The patient's heart rate during scanning for most scanners (at the time of this writing) should be less than 65 beats/min and optimally less than 60 beats/min.
- If the patient's heart rate and/or rhythm remain unfavorable (given the site's scanner hardware) despite all efforts of heart rate control, alternative diagnostic imaging strategies should be considered, although coronary CTA may remain the appropriate test in some instances.
- The imaging physician has to be familiar with the specific technical limitations and strengths of the site's CT scanner system and has to adjust patient selection, heart rate control, and acquisition protocols accordingly.

## 7. Image reconstruction and post processing

### 7.1. Introduction

The immediate result of a CT scan is a raw attenuation data set, not actual viewable images. To create viewable images, the raw data are converted into digital images in which each pixel is assigned a digital numerical value (CT value), expressed in Hounsfield units. The computation of these CT values is referred to as axial image reconstruction and typically occurs by a process known as filtered backprojection. By various means, interventions in the reconstruction method influence the final appearance of the axial images, in terms of image quality, image artifact, edge enhancement, and resolution. In most cases axial image reconstruction is preprogrammed into the scan protocol and takes place with minimal input from a technologist. However, it is still necessary to be familiar with the process to build the scan protocols and to adjust them when necessary.

This section addresses the factors that influence the final resulting image data set and makes recommendations for certain actions in certain scenarios.

### 7.2. Half-scan versus full-scan reconstruction

Using a full 360 degrees of projections to reconstruct an axial image is referred to as a full-scan reconstruction. Because diametrically opposed projections are essentially identical, images in cardiac imaging are most commonly reconstructed using only a half set of projections, known as half-scan reconstruction. This has the advantage of improving temporal resolution and reducing reconstruction time.

### 7.3. Field of view

The field of view is reflected in the dimensions (diameter or length of edge) of the resultant axial image. It typically includes only a portion of the scan field to best match the size of the image pixels to the resolution of the scan. Current CT scanners have a resolution of approximately 0.4–0.5 mm; hence, an image that is 512 pixels in diameter (using the standard  $512 \times 512$  matrix) should be reconstructed with a field of view of 200–250 mm or less. Using a larger field of view reduces the spatial resolution of the data set.

### 7.4. Slice width

In axial mode scanning, slice width is set before the scan by the scan collimation. In helical mode acquisition, the reconstructed slice width can be adjusted after data acquisition. The selection of slice width, or slice thickness, carries significant implications for image quality because of volume averaging. Thicker slices have lower image noise, but also lower spatial resolution compared with thinner slices. Axial image reconstruction should therefore typically use very thin slice width, almost always  $< 1$  mm. Use of the minimum possible slice width may not always be ideal. For example, in obese patients, it may be preferable to reconstruct images at a thickness that is larger than the collimation to reduce image noise.

### 7.5. Reconstruction kernel

The reconstruction kernel is the mathematical algorithm used to compute the CT values of the pixels within the CT data set. “Soft” kernels produce an image of lower noise and lower spatial resolution, whereas “sharp” kernels increase resolution at the cost of higher image noise. In addition, algorithms can be designed specifically for reducing metal artifact or calcium blooming or to enhance the appearance of contrast and the vascular structures.<sup>60</sup> Understanding these differences is essential to selecting and applying the correct kernel for a given set of patient factors (eg, body habitus) and clinical scenarios (eg, imaging heavily calcified arteries). It is important to realize that attenuation values may vary from one scanner to the next.<sup>61</sup>

### 7.6. Cardiac phase

The heart's continual cyclical movement provides brief periods of minimal motion during end systole and late diastole. Proper selection of these time points for motion-free image reconstruction is crucial to obtaining high-quality diagnostic images.<sup>62</sup> Identification of this timeframe is based on cardiac cycle length and is expressed as a percentage of the cardiac cycle length or as an absolute duration of time (in milliseconds) relative to the QRS complex. The use of absolute time instants for image reconstruction (eg, 700 milliseconds after the R peak) interval may produce better image quality but has not been shown to make a difference in diagnostic accuracy.<sup>63</sup> The optimal phase for reconstruction depends on the heart rate during the acquisition, and this holds true for dual-source as well as single-source scanners.<sup>64,65</sup> There is general agreement that at lower heart rates ( $< 65$  beats/min) the optimal phase will be found in late diastole, whereas at higher heart rates ( $> 65$ – $70$  beats/min) the optimal phase will more frequently (but not always) occur at end systole.<sup>66–69</sup> Importantly, even a slight shift of this timeframe of as little as 50 milliseconds away from the optimal timeframe can create artifacts that mimic coronary stenosis.<sup>70–73</sup> Therefore, if the original data set is not free of motion artifact, several data sets must be reconstructed at different timeframes of the cardiac cycle. In these cases, it is not sufficient to rely solely on phases automatically selected by the reconstruction software or on a predetermined, fixed range of phases applied to all cases. If motion artifact is present, tailored image reconstruction must be repeated in intervals that correspond to 5% of the cardiac cycle or less until a data set without motion artifact is obtained or the phase with least motion is identified. It may be necessary to use different phases of the cardiac cycle for various segments of the coronary arteries.

### 7.7. Multi-cycle reconstruction

Multi-cycle reconstruction takes advantage of the multi-detector scanner architecture to improve temporal resolution. Because multiple detector rows are stacked in the z-axis, any given location in the body will pass multiple detector rows at the same point in the cardiac cycle but during different, contiguous heart beats. Rather than using the half-scan data from one cardiac cycle to reconstruct an axial image, multi-cycle reconstruction uses data from multiple (contiguous) cardiac cycles and pieces them together to recreate the half-scan of data and hence the axial image. This reduces the acquisition time within each cardiac cycle and improves temporal resolution and image quality. Especially at higher heart rates, the use of multi-cycle reconstruction can significantly improve image quality and diagnostic yield and accuracy.<sup>71,74</sup> Caveats regarding this technique include the requirement of a regular cardiac rhythm and the assumption (not always true) that the cardiac position will not vary between heart beats during acquisition.

### 7.8. ECG editing

In cardiac CT, acquisition of ECG data occurs simultaneously with the acquisition of attenuation data, and the axial reconstruction process uses both sets of data. Hence, the ECG data set must be reviewed if artifacts occur in the reconstructed image data set. If the capability exists, errors that are due to incorrect gating should be corrected by “editing” the ECG data and “tagging” or “removal” of ectopic beats should be performed if they cause artifact. This can often salvage what would otherwise be an uninterpretable scan.<sup>75</sup>

### 7.9. Image review

It is recommended that axial images should be reviewed immediately after reconstruction (which can be done by the technologist) while the patient is still on the scanner table to confirm sufficient quality of data acquisition.

### Recommendations

- Half-scan reconstruction should be used by default for all axial reconstruction.
- The reconstructed field of view should be reduced to maximize number of pixels devoted to depiction of the heart, usually a FOV of 200–250mm for coronary CTA studies of native coronary arteries.
- If extracardiac structures are of interest, then a second data set with a larger FOV (x–y plane) should be reconstructed.
- Axial images should be reconstructed with a slice width < 1.0mm for most coronary CTA studies of native coronary arteries. Minimum slice thickness (0.5–0.6mm) should be considered for studies that require maximum spatial resolution, insofar as image noise permits. A thicker slice width (1.0–1.5mm) should be considered in obese patients to reduce image noise resulting from body habitus.
- A slice increment of 50% of the slice width should be used.
- A semi-sharp reconstruction kernel should be used for most patients. For cases that require maximum spatial resolution, a sharp kernel may be used to reduce blooming and to increase edge definition. For obese patients, a soft or smooth kernel may be used to reduce image noise.
- A sufficient number of phases should be reconstructed to find the phase with the least amount of cardiac motion artifact.
- Multi-cycle reconstruction should be considered, especially at higher heart rates, to improve temporal resolution and to improve image quality.
- ECG editing, if available, should be used to correct errors or artifacts occurring during acquisition and to designate ectopic beats for exclusion or special handling during data reconstruction.

### 8. Conclusion

Great advances in MDCT technology in the past 5 years have resulted in the ability now to reliably identify and evaluate coronary disease using coronary CT angiography.

Impressive advances in the technology should not, however, beguile the practitioner into a belief that the performance of the technique is necessarily straightforward in all cases. For consistently successful imaging, interpretation, and diagnosis, a clear understanding of the technique’s capabilities and limitations, and an appreciation of the details of patient selection, patient preparation, scan acquisition, and image reconstruction are required. The theme throughout this document is that supervision and care must be taken at every step in the process to ensure consistently high-quality results in patient after patient. These guidelines serve as a starting point, but proper execution of the procedure in any given patient requires both expertise on the part of all involved practitioners and staff, and vigilance by all for the appearance of variants in clinical scenarios and patient factors which will require tailoring of the technique in some, if not most, cases.

### References

1. Hendel RC, Patel MR, Kramer CM, Poon M, Hendel RC, Carr JC, Gerstad NA, Gillam LD, Hodgson JM, Kim RJ, Kramer CM, Lesser JR, Martin ET, Messer JV, Redberg RF, Rubin GD, Rumsfeld JS, Taylor AJ, Weigold WG, Woodard PK, Brindis RG, Hendel RC, Douglas PS, Peterson ED, Wolk MJ, Allen JM, Patel MR: ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group: American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. *J Am Coll Cardiol.* 2006;48:1475–97.
2. Budoff MJ, Cohen MC, Garcia MJ, Hodgson JM, Hundley WG, Lima AC, Manning WJ, Pohost GM, Raggi PM, Rodgers GP, Rumberger JA, Taylor AJ: ACC/AHA clinical competence statement on cardiac imaging with computed tomography and magnetic resonance: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence (ACC/AHA Committee on CV Tomography). *J Am Coll Cardiol.* 2005;46:383–402.
3. Rubin GD, Bluemke DA, Duerinckx AJ, Flamm SD, Grist TM, Jacobs JE, Lavelle MT, Schoepf J, Stillman AE, Woodard PK: ACR Committee on Cardiac Imaging. Practice guideline for the performance and interpretation of cardiac computed tomography (CT). (Res. 10, 16g, 17, 34, 35, 36–2006). In: Practice guidelines and technical standards. Reston, VA: American College of Radiology, 2008. p. 421–430.
4. Valentin J: Pregnancy and medical radiation: ICRP publication 84. *Ann ICRP.* 2000;30(1):1–39.
5. Webb JA, Thomsen HS, Morcos SK: Members of Contrast Media Safety Committee of European Society of Urogenital Radiology (ESUR). The use of iodinated and gadolinium contrast media during pregnancy and lactation. *Eur Radiol.* 2005;15:1234–40.
6. Greenberger P, Patterson R: Prednisone-diphenhydramine regimen prior to use of radiographic contrast media. *J Allergy Clinical Immunol.* 1979;63:295.
7. Licker BM, Cypel YS, Weinreb JC: IV contrast administration for CT: a survey of practices for the screening and prevention of contrast nephropathy. *AJR Am J Roentgenol.* 2006;186:1651–8.
8. Lee JK, Warshauer DM, Bush WH Jr., McClennan BL, Choyke PL: Determination of serum creatinine level before intravenous

- administration of iodinated contrast medium: a survey. *Invest Radiol.* 1995;30:700–5.
9. Briguori C, Airolidi F, D'Andrea D, Bonizzoni E, Morici N, Focaccio A, Michev I, Montorfano M, Carlino M, Cosgrave J, Ricciardelli B, Colombo A: Renal insufficiency following contrast media administration trial (REMEDIAL): a randomized comparison of 3 preventive strategies. *Circulation.* 2007;115:1211–7.
  10. Briguori C, Columbo A, Violante A, Balestrieri P, Manganelli F, Paolo Elia P, Golia B, Lepore S, Riviezzo G, Scarpato P, Focaccio A, Librera M, Bonizzoni E, Ricciardelli B: Standard vs double dose of N-acetylcysteine to prevent contrast agent associated nephrotoxicity. *Eur Heart J.* 2004;25:206–11.
  11. Lee PT, Chou KJ, Liu CP, Mar GY, Chen CL, Hsu CY, Fang HC, Chung HM: Renal protection for coronary angiography in advanced renal failure patients by prophylactic hemodialysis: a randomized controlled trial. *J Am Coll Cardiol.* 2007;50:1015–20.
  12. Marenzi G, Assanelli E, Marana I, Lauri G, Campodonico J, Grazi M, De Metrio M, Galli S, Fabbiochi F, Montorsi P, Veglia F, Bartorelli AL: N-acetylcysteine and contrast-induced nephropathy in primary angioplasty. *N Engl J Med.* 2006;354:2773–82.
  13. Barrett BJ, Katzberg RW, Thomsen HS, Chen N, Sahani D, Soulez G, Heiken JP, Lepanto L, Ni ZH, Nelson R: Contrast-induced nephropathy in patients with chronic kidney disease undergoing computed tomography: a double-blind comparison of iodixanol and iopamidol. *Invest Radiol.* 2006;41:815–21.
  14. El-Hajjar M, Bashir I, Khan M, Min J, Torosoff M, DeLago A: Incidence of contrast-induced nephropathy in patients with chronic renal insufficiency undergoing multidetector computed tomographic angiography treated with preventive measures. *Am J Cardiol.* 2008;102:353–6.
  15. Ahuja TS, Niazi N, Agraharkar M: Contrast-induced nephrotoxicity in renal allograft recipients. *Clin Nephrol.* 2000;54:11–4.
  16. Poletti PA, Saudan P, Platon A, Mermillod B, Sautter AM, Vermeulen B, Sarasin FP, Becker CD, Martin PY: N-acetylcysteine and emergency CT: use of serum creatinine and cystatin C as markers of radiocontrast nephrotoxicity. *AJR Am J Roentgenol.* 2007;189:687–92.
  17. Schmidt P, Pang D, Nykamp D, Knowlton G, Jia H: N-acetylcysteine and sodium bicarbonate versus n-acetylcysteine and standard hydration for the prevention of radiocontrast-induced nephropathy following coronary angiography. *Ann Pharmacother.* 2007;41:46–50.
  18. Solomon R: Contrast media nephropathy: how to diagnose and how to prevent? *Nephrol Dial Transplant.* 2007;22:1812–5.
  19. Zagler A, Azadpour M, Mercado C, Hennekens CH: N-acetylcysteine and contrast-induced nephropathy: a meta-analysis of 13 randomized trials. *Am Heart J.* 2006;151:140–5.
  20. Brodoefel H, Reimann A, Heuschmid M, Küttner A, Beck T, Burgstahler C, Claussen CD, Schroeder S, Kopp AF: Non-invasive coronary angiography with 16-slice spiral computed tomography: image quality in patients with high heart rates. *Eur Radiol.* 2006;16:1434–41.
  21. Cademartiri F, Mollet NR, Runza G, Belgrano M, Malagutti P, Meijboom BW, Midiri M, Feyter PJ, Krestin GP: Diagnostic accuracy of multislice computed tomography coronary angiography is improved at low heart rates. *Int J Cardiovasc Imaging.* 2006;22:101–5.
  22. Hoffmann MH, Shi H, Mancke R, Schmid FT, De Vries L, Grass M, Brambs HJ, Aschoff AJ: Noninvasive coronary angiography with 16-detector row CT: effect of heart rate. *Radiology.* 2005;234:86–97.
  23. Le Jemtel TH, Padeletti M, Jelic S: Diagnostic and therapeutic challenges in patients with coexistent chronic obstructive pulmonary disease and chronic heart failure. *J Am Coll Cardiol.* 2007;49:171–82.
  24. Dewey M, Hoffmann H, Hamm B: Multislice CT coronary angiography: effect of sublingual nitroglycerine on the diameter of coronary arteries. *ROFO Fortschr Geb Rontgenstr Nuklearmed.* 2006;178:600–4.
  25. Decramer I, Vanhoenacker PK, Sarno G, Van Hoe L, Bladt O, Wijns W, Parizel PM: Effects of sublingual nitroglycerin on coronary lumen diameter and number of visualized septal branches on 64-MDCT angiography. *AJR Am J Roentgenol.* 2008;190:219–25.
  26. Wang G, Vannier MW: Spatial variation of section sensitivity profile in spiral computed tomography. *Med Phys.* 1994;21:1491–7.
  27. Ohnesorge B, Flohr T, Becker C, Kopp AF, Schoepf UJ, Baum U, Knez A, Klingenberg-Regn K, Reiser MF: Cardiac imaging by means of electrocardiographically gated multisection spiral CT: initial experience. *Radiology.* 2000;217(2):564–71.
  28. Halliburton SS, Abbara S: Practical tips and tricks in cardiovascular computed tomography: patient preparation for optimization of cardiovascular CT data acquisition. *J Cardiovasc Comput Tomogr.* 2007;1:62–5.
  29. Bae KT, Tran HQ, Heiken JP: Multiphasic injection method for uniform prolonged vascular enhancement at CT angiography: pharmacokinetic analysis and experimental porcine model. *Radiology.* 2000;216:872–80.
  30. Fleischmann D, Rubin GD, Bankier AA, Hittmair K: Improved uniformity of aortic enhancement with customized contrast medium injection protocols at CT angiography. *Radiology.* 2000;214:363–71.
  31. Haage P, Schmitz-Rode T, Hubner D, Piroth W, Gunther RW: Reduction of contrast material dose and artifacts by a saline flush using a double power injector in helical CT of the thorax. *AJR Am J Roentgenol.* 2000;174:1049–53.
  32. Hopper KD, Mosher TJ, Kasales CJ, TenHave TR, Tully DA, Weaver JS: Thoracic spiral CT: delivery of contrast material pushed with injectable saline solution in a power injector. *Radiology.* 1997;205:269–71.
  33. Segal AJ, Ellis JH, Baumgartner BR, Choyke PL, Cohan RH, Costouros NG, Feinstein KA, Fielding JR, Jenkins R, Krecke KN, Sandler CM, Spinosa DJ, Spring DB, Wasserman NF: ACR Committee on Drugs and Contrast Media. Practice guideline for the use of intravascular contrast media. (Res. 38 – 2007). In: Practice guidelines and technical standards. Reston, VA: American College of Radiology, 2008. p. 73–8.
  34. Segal AJ, Ellis JH, Baumgartner BR, Choyke PL, Cohan RH, Cohen M, Feinstein KA, Fielding JR, Jenkins R, Krecke KN, Sandler CM, Spinosa DJ, Spring DB, Wasserman NF: ACR Committee on Drugs and Contrast Media: Manual on contrast media. Version 6. . Reston, VA: American College of Radiology; 2008.
  35. Brenner DJ, Hall EJ: Computed tomography: an increasing source of radiation exposure. *New Engl J Med.* 2007;357:2277–84.
  36. Overbeek FJ, Pauwels EK, Bloem JL, Camps JA, Geleijns J, Broerse JJ: Somatic effects in nuclear medicine and radiology. *Appl Radiat Isot.* 1999;50:63–72.
  37. Brenner DJ, Doll R, Goodhead DT, Hall EJ, Land CE, Little JB, Lubin JH, Preston DL, Preston RJ, Puskin JS, Ron E, Sachs RK, Samet JM, Setlow RB, Zaider M: Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. *Proc Natl Acad Sci U S A.* 2003;100:13761–6.
  38. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation; Nuclear and Radiation Studies Board: Division on Earth and Life Studies, National Research Council of the National Academies: Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2. Washington, DC: The National Academies Press; 2006.
  39. Don S: Radiosensitivity of children: potential for overexposure in CR and DR and magnitude of doses in ordinary radiographic examinations. *Ped Radiol.* 2004;34(Suppl 3):S167–72.
  40. Nickoloff EL, Alderson PO: A comparative study of thoracic radiation doses from 64-slice cardiac CT. *Br J Radiol.* 2007;80:537–44.
  41. Einstein AJ, Henzlova MJ, Rajagopalan S: Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. *JAMA.* 2007;298:317–23.
  42. Rybicki FJ, Otero HJ, Steigner ML, Vorobiof G, Nallamshetty L, Mitsouras D, Ersoy H, Mather RT, Judy PF, Cai T, Coyner K, Schultz K, Whitmore AG, Di Carli MF: Initial evaluation of coronary images from 320-detector row computed tomography. *Int J Cardiovasc Imaging.* 2008;24:535–46.
  43. Rehani MM, Bongartz G, Kalender W, Golding SJ, Gordon L, Murakami T, Shrimpton P: Managing patient dose in computed tomography. *Ann ICRP.* 2000;30(4):7–45.

44. Hausleiter J, Meyer T, Hadamitzky M, Huber E, Zankl M, Martinoff S, Kastrati A, Schomig A: Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. *Circulation*. 2006;113:1305–10.
45. Siegel MJ, Schmidt B, Bradley D, Suess C, Hildebolt C: Radiation dose and image quality in pediatric CT: effect of technical factors and phantom size and shape. *Radiology*. 2004;233:515–22.
46. Hermann F, Martinoff S, Meyer T, Hadamitzky M, Jiang C, Hendrich E, Hausleiter J: Reduction of radiation dose estimates in cardiac 64-slice CT angiography in patients after coronary artery bypass graft surgery. *Invest Radiol*. 2008;43:253–60.
47. Shuman WP, Branch KR, May JM, Mitsumori LM, Lockhart DW, Dubinsky TJ, Warren BH, Caldwell JH: Prospective versus retrospective ECG gating for 64-detector CT of the coronary arteries: comparison of image quality and patient radiation dose. *Radiology*. 2008;248:431–7.
48. Husmann L, Valenta I, Gaemperli O, Adda O, Treyer V, Wyss CA, Veit-Haibach P, Tatsugami F, von Schulthess GK, Kaufmann PA: Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. *Eur Heart J*. 2008;29:191–7.
49. Scheffel H, Alkadhi H, Leschka S, Plass A, Desbiolles L, Guber I, Krauss T, Gruenfelder J, Genoni M, Luescher TF, Marincek B, Stolzmann P: Low-dose CT coronary angiography in the step-and-shoot mode: diagnostic performance. *Heart*. 2008;94:1132–7.
50. Geleijns J, Salvado Artells M, Veldkamp WJ, Lopez Tortosa M, Calzado Cantera A: Quantitative assessment of selective in-plane shielding of tissues in computed tomography through evaluation of absorbed dose and image quality. *Eur Radiol*. 2006;16:2334–40.
51. Donadieu J, Roudier C, Saguintaah M, Maccia C, Chiron R: Estimation of the radiation dose from thoracic CT scans in a cystic fibrosis population. *Chest*. 2007;132:1233–8.
52. Bae KT: Peak contrast enhancement in CT and MR angiography: when does it occur and why? Pharmacokinetic study in a porcine model. *Radiology*. 2003;227:809–16.
53. McCollough C, Cody D, Edyvean S, Geise R, Gould B, Keat N, Huda W, Judy P, Kalender W, McNitt-Gray M, Morin R, Payne T, Stern S, Rothenberg LAAPM Task Group 23: CT dosimetry. Diagnostic Imaging Council CT Committee: The Measurement, reporting, and management of radiation dose in CT. College Park, MD: American Association of Physicists in Medicine; 2008. AAPM Report No. 96.
54. Hunold P, Vogt FM, Schmermund A, Debatin JF, Kerckhoff G, Budde T, Erbel R, Ewen K, Barkhausen J: Radiation exposure during cardiac CT: effective doses at multi-detector row CT and electron-beam CT. *Radiology*. 2003;226:145–52.
55. Pundziute G, Schuijf JD, Jukema JW, Lamb HJ, de Roos A, van der Wall EE, Bax JJ: Impact of coronary calcium score on diagnostic accuracy of multislice computed tomography coronary angiography for detection of coronary artery disease. *J Nucl Cardiol*. 2007;14:36–43.
56. Cordeiro MA, Miller JM, Schmidt A, Lardo AC, Rosen BD, Bush DE, Brinker JA, Bluemke DA, Shapiro EP, Lima JA: Non-invasive half millimetre 32 detector row computed tomography angiography accurately excludes significant stenoses in patients with advanced coronary artery disease and high calcium scores. *Heart*. 2006;92:589–97.
57. Rumberger JA, Simons DB, Fitzpatrick LA, Sheedy PF, Schwartz RS: Coronary artery calcium area by electron-beam computed tomography and coronary atherosclerotic plaque area. A histopathologic correlative study. *Circulation*. 1995;92:2157–62.
58. Oncel D, Oncel G, Tastan A: Effectiveness of dual-source CT coronary angiography for the evaluation of coronary artery disease in patients with atrial fibrillation: initial experience. *Radiology*. 2007;245:703–11.
59. Scheffel H, Alkadhi H, Plass A, Vachenaier R, Desbiolles L, Gaemperli O, Schepis T, Frauenfelder T, Schertler T, Husmann L, Gruenfelder J, Genoni M, Kaufmann PA, Marincek B, Leschka S: Accuracy of dual-source CT coronary angiography: first experience in a high pre-test probability population without heart rate control. *Eur Radiol*. 2006;16:2739–47.
60. Cademartiri F, Runza G, Mollet NR, Luccichenti G, Belgrano M, Somers P, Knaapen M, Verheye S, Bruining N, Hamers R, Midiri M, DeFeyter PJ, Krestin GP: Influence of increasing convolution kernel filtering on plaque imaging with multislice CT using an ex-vivo model of coronary angiography. *Radiol Med (Torino)*. 2005;110:234–40.
61. Birnbaum BA, Hindman N, Lee J, Babb JS: Multi-detector row CT attenuation measurements: Assessment of intra- and interscanner variability with an anthropomorphic body CT phantom. *Radiology*. 2007;242:109–19.
62. Dewey M, Teige F, Rutsch W, Schink T, Hamm B: CT coronary angiography: influence of different cardiac reconstruction intervals on image quality and diagnostic accuracy. *Eur J Radiol*. 2008;67:92–9.
63. Herzog C, Arning-Erb M, Zangos S, Eichler K, Hammerstingl R, Dogan S, Ackermann H, Vogl TJ: Multi-detector row CT coronary angiography: influence of reconstruction technique and heart rate on image quality. *Radiology*. 2006;238:75–86.
64. Husmann L, Leschka S, Desbiolles L, Schepis T, Gaemperli O, Seifert B, Cattin P, Frauenfelder T, Flohr TG, Marincek B, Kaufmann PA, Alkadhi H: Coronary artery motion and cardiac phases: dependency on heart rate and implications for CT image reconstruction. *Radiology*. 2007;245(2):567–76.
65. Leschka S, Wildermuth S, Boehm T, Desbiolles L, Husmann L, Plass A, Koepfli P, Schepis T, Marincek B, Kaufmann PA, Alkadhi H: Noninvasive coronary angiography with 64-section CT: effect of average heart rate and heart rate variability on image quality. *Radiology*. 2006;241:378–85.
66. Vembar M, Walker MJ, Johnson PC: Cardiac imaging using multislice computed tomography scanners: technical considerations. *Coron Artery Dis*. 2006;17:115–23.
67. Wintersperger BJ, Nikolaou K, von Ziegler F, Johnson T, Rist C, Leber A, Flohr T, Knez A, Resier MF, Becker CR: Image quality, motion artifacts, and reconstruction timing of 64-slice coronary computed tomography angiography with 0.33-second rotation speed. *Invest Radiol*. 2006;41:436–42.
68. Nagatani Y, Takahashi M, Takazakura R, Nitta N, Murata K, Ushio N, Matsuo S, Yamamoto T, Horie M: Multidetector-row computed tomography coronary angiography: optimization of image reconstruction phase according to the heart rate. *Circ J*. 2007;71:112–21.
69. Seifarth H, Wienbeck S, Püsken M, Juergens KU, Maintz D, Vahlhaus C, Heindel W, Fischbach R: Optimal systolic and diastolic reconstruction windows for coronary CT angiography using dual-source CT. *AJR Am J Roentgenol*. 2007;189:1317–23.
70. Leschka S, Husmann L, Desbiolles LM, Gaemperli O, Schepis T, Koepfli P, Boehm T, Marincek B: Kaufmann PA Alkadhi H: Optimal image reconstruction intervals for non-invasive coronary angiography with 64-slice CT. *Eur Radiol*. 2006;16:1964–72.
71. Dewey M, Teige F, Laule M, Hamm B: Influence of heart rate on diagnostic accuracy and image quality of 16-slice CT coronary angiography: comparison of multisection and halfscan reconstruction approaches. *Eur Radiol*. 2007;17:2829–37.
72. Weininger M, Ritter C, Beer M, Hahn D, Beissert M: Evaluation of the optimal image reconstruction interval for coronary artery imaging using 64-slice computed tomography. *Acta Radiol*. 2007;48:620–7.
73. Frydrychowicz A, Pache G, Saueressig U, Foll D, Kotter E, Langer M, Bley TA: Comparison of reconstruction intervals in routine ECG-pulsed 64-row MSCT coronary angiography in frequency controlled patients. *Cardiovasc Intervent Radiol*. 2007;30:79–84.
74. Herzog C, Nguyen SA, Savino G, Zwerner PL, Doll J, Nielsen CD, Flohr TG, Vogl TJ, Costello P, Schoepf UJ: Does two segment image reconstruction at 64-section CT coronary angiography improve image quality and diagnostic accuracy? *Radiology*. 2007;244:121–9.
75. Cademartiri F, Mollet NR, Runza G, Baks T, Midiri M, McFadden EP, Flohr TG, Ohnesorge B, de Feyter PJ, Krestin GP: Improving diagnostic accuracy of MDCT coronary angiography in patients with mild heart rhythm irregularities using ECG editing. *AJR Am J Roentgenol*. 2006;186:634–8.