The What and Why of Cardiac CT Angiography: Data Interpretation and Clinical Practice Integration

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Noninvasive visualization of the coronary arteries is the holy grail of cardiac imaging. Cardiac catheterization (CC), the historic gold standard for coronary imaging, is invasive, costly, and often performed unnecessarily. Cardiac computed tomographic angiography (CCTA) is a widely available, cost-effective imaging modality that effectively images the coronary arteries. The most appropriate patient for a CCTA-guided approach to the evaluation of chest pain is the symptomatic patient at low to intermediate risk. Data are rapidly evolving to further validate the accuracy, prognostic ability, and cost-effectiveness of this technique. The current landscape of the American medical system and the rising cost of United States health care have led to skepticism concerning CCTA and its potential misuse. Technological misunderstanding and concern about excessive radiation exposure also threaten its growth. When used properly by appropriately trained physicians, CCTA adds significant value to the evaluation of chest pain and to the diagnosis of coronary artery disease. [Rev Cardiovasc Med. 2009;10(3):xx-xx]

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Symptoms referable to the cardiovascular system represent only 0.2% of all outpatient clinic visits in the United States. This small subset of patients accounts for more than $2 billion of the $13 billion in total US health care yearly expenditures for outpatient clinic visits.1-3 Many noninvasive diagnostic tests may be used for chest pain patients with low to intermediate likelihood of disease. These include stress electrocardiography, stress perfusion single-photon
emission computed tomography (SPECT) imaging, and stress echocardiography. Exercise testing with or without echocardiography or SPECT is indirect and of limited diagnostic accuracy. Although these traditional, noninvasive tests may provide complementary prognostic, anatomic, and physiologic information, unnecessary repetitive diagnostic testing and the unnecessary cardiac catheterization (CC) that may result from indeterminate or borderline noninvasive test results are possible reasons for such a large expenditure in a small subset of patients.

The utility of a diagnostic testing strategy should account not only for the accuracy, prognostic ability, risk, and expense of the proposed test, but should also take into account the prevalence of disease in the tested population. It has been documented, for example, that noninvasive testing is more cost-effective in low-risk patient populations with chest pain, whereas CC is more cost-effective in high-risk patients. Furthermore, logic dictates that diagnostic tests likely to rule out or rule in multiple possible diagnoses may be more valuable than those that exclude or include only 1 diagnosis.

Advances in cardiac computed tomographic angiography (CCTA) result in reproducible and accurate images of the coronary arteries. Quick gantry rotation times of 360 ms or less and increasing numbers of detector rows of up to 320 have effectively frozen the heart in time, resulting in effective coronary artery imaging (Figure 1). A spatial resolution of near 0.4 mm permits visualization of arteries sized 1.5 mm or larger. Reduced detector size and collimation width result in nearly equal through-plane and in-plane spatial resolution, resulting in isotropic voxels that are necessary for distortion-free manipulation of 3-dimensional cardiac computed tomography (CT) data sets.

Advanced workstation capabilities allow the operator to manipulate these exquisite images in 3 dimensions. Thus, small structures such as coronary arteries may be precisely analyzed as they move through multiple imaging planes. Multiple reconstruction algorithms such as volume rendered 3-dimensional reconstructions, maximum intensity projections, and curved multiplanar reformatting add to the analytic accuracy of this technique (Figure 2).

Finally, improvements in imaging algorithms, such as prospective gating (“step and shoot” technique), as well as more dose-saving, individualized CCTA protocols, result in significantly less radiation exposure. In addition, CCTA concomitantly images the myocardium, the great vessels, the pulmonary arteries, the pericardium, the cardiac valves, and other chest and upper abdominal structures, which may ultimately help explain the etiology of chest pain and exclude many diagnostic considerations.

Despite these favorable characteristics, CCTA is often criticized. Possible reasons for this criticism include unfair interpretation and evaluation of modern data and poor understanding of the relative strengths and weaknesses of CCTA, as well as a misunderstanding of the most appropriate patient type for CCTA. Furthermore, there is a clear hesitance among public and private payers to add CCTA to their coverage plans. In addition, critics underestimate the caution and responsibility with which CCTA experts are advancing this field. This responsible approach includes a rapidly growing society dedicated to CCTA (the Society of Cardiovascular Computed Tomography [SCCT]), self-imposed...
Clinical Integration Model.

Cardiac CT Angiography

Validation Data

Native Coronary Arteries

To become clinically trusted and well accepted in the medical community, new diagnostic testing modalities must be subjected to and must withstand strict scientific rigor to determine accuracy, prognostic ability, safety, and cost-effectiveness. Validation studies are the first piece to a complicated puzzle of clinical evaluation. Although these proof-of-concept studies are necessary and important, they are only the first step toward the clinical relevance and acceptance of any new diagnostic test. The interpretation and judgment of these initial scientific studies must account for this important concept.

Two important meta-analyses by Hamon and colleagues6,7 have been published to assess the accuracy of CCTA. These analyses have pooled the early single-center studies comparing 16-slice or greater CCTA to the gold standard of CC where coronary stenoses of 50% or greater were considered significant. In the first of these studies using scanners of 16 slices or greater,6 only 4.2% of segments and 0.017% of patients were excluded for unsuccessful imaging.

The pooled accuracy data from this study are summarized in Table 1. The subsequent analysis by the same group7 compared 16-slice with 64-slice CCTA data. The mean rates of unassessable segments ranged from 1% to 29% in 16-slice scanners versus 0% to 12% in 64-slice scanners. Table 2 depicts the pooled accuracy data from this second meta-analysis.

Take-home points from these 2 meta-analyses are that the power of CCTA lies in its negative predictive value (NPV), or its ability to rule out disease, and that the performance of CCTA improves with 64-slice CCTA when compared with 16-slice CCTA, especially with regard to sensitivity. The number of evaluable segments also improves dramatically with 64-slice versus 16-slice CCTA. Most likely, this finding results from improved coverage of the 64-slice scanners, resulting in a reduced scan time (fewer heart beats needed to complete the scan). Thus, arrhythmia and breathing artifacts are less problematic. Finally, the per-vessel and, more importantly, per-patient analyses fair better than per-segment.

and rigid clinical practice training guidelines for those already in clinical practice, and, for fellows in training,13,12 the establishment of a program to endorse private CCTA training courses,13 the establishment of a CCTA certification board,14 the pre-emptive development of CCTA appropriateness criteria,15 and the creation of the Journal of Cardiovascular Computed Tomography to promote CCTA research and education.

Akin to all important technological innovations, future studies are necessary to further define and refine the role of CCTA. However, its place as a currently valuable diagnostic and prognostic cardiovascular imaging tool is sound. Yet critics attempt to hold CCTA to a much higher standard than any other imaging test in the history of medicine by demanding clinical outcomes data for a diagnostic test meant to identify and not treat disease.7

Demand for proof that CCTA, on its own, can reduce the morbidity and mortality associated with coronary artery disease (CAD) is not reasonable because it is the treatments such as lipid modification, antiplatelet therapies, β-blockers, and angiotensin-converting enzyme inhibitors, along with lifestyle modifications such as exercise, weight reduction, and smoking cessation, that reduce cardiac event rates. The diagnostic examination itself does not reduce possible negative outcomes. An analogy would be mammography. It is not the mammogram that improves outcomes. On the contrary, the early treatment of the identified breast malignancy is what saves lives. Therefore, this is clearly an unreasonable expectation for a diagnostic imaging modality.

This article will review current data, rebut criticisms regarding CCTA, and propose a practical CCTA clinical integration model.

Table 1

Pooled Accuracy Data From a Meta-Analysis of CCTA Examinations

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>PPV (95% CI)</th>
<th>NPV (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Segment</td>
<td></td>
<td></td>
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<tr>
<td>(n = 22,798)</td>
<td>81% (72%-89%)</td>
<td>93% (90%-97%)</td>
<td>67.8% (57.6%-78%)</td>
<td>96.5% (94.7%-98.3%)</td>
</tr>
<tr>
<td>Per Vessel</td>
<td>82% (80%-85%)</td>
<td>91% (90%-92%)</td>
<td>81% (78%-83%)</td>
<td>92% (91%-93%)</td>
</tr>
<tr>
<td>(n = 2726)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per Patient</td>
<td>96% (94%-98%)</td>
<td>74% (65%-84%)</td>
<td>83% (76%-90%)</td>
<td>94% (89%-99%)</td>
</tr>
<tr>
<td>(n = 1570)</td>
<td></td>
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</table>

*The scanners were 16 slices or greater.

CCTA, cardiac computed tomographic angiography; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

Reprinted with permission from Hamon M et al.6
evaluations (Figure 3). For purposes of clinical decision making, the per-patient data are of most interest because these data drive the patient management decisions.

Three important multicenter prospective studies have also been performed to evaluate the accuracy of CCTA. The Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography (ACCURACY) study\textsuperscript{16} was a prospective, multicenter study evaluating the use of 64-slice CCTA in adults presenting with chest pain who were referred for CC. A total of 16 sites and 232 patients participated. All scans were evaluated on a per-patient and per-segment basis. No vessel segments were deemed unevaluable. All segments were included regardless of patient or vessel calcium score, and patients were not excluded on the basis of body mass index.

The prevalence of obstructive CAD in this population was low, at 20%. For stenoses greater than 50%, the per-patient and per-vessel analyses were as follows: 93% versus 84% for sensitivity, 82% versus 91% for specificity, 62% versus 51% for positive predictive value (PPV), and 97% versus 98% for NPV. The reduced PPV may reflect the low prevalence of disease.

The Coronary Evaluation on 64 (CORE 64) study,\textsuperscript{17} a prospective, multicenter study evaluating

\begin{table}[h]
\centering
\caption{Pooled Accuracy Data From a Meta-Analysis Comparing 16-Slice CCTA Scanners and 64-Slice CCTA Scanners}
\begin{tabular}{|c|c|c|c|c|}
\hline
 & Sensitivity & Specificity & PPV & NPV \\
 & (95\% CI) & (95\% CI) & (95\% CI) & (95\% CI) \\
\hline
\textbf{16-Slice} & & & & \\
\hline
Per Segment & 77\% & 91\% & 60\% & 96\% \\
(n = 16,510) & (75\%-79\%) & (91\%-92\%) & (59\%-62\%) & (96\%-96\%) \\
\hline
Per Patient & 95\% & 69\% & 79\% & 92\% \\
(n = 1292) & (93\%-96\%) & (66\%-73\%) & (76\%-82\%) & (88\%-94\%) \\
\hline
\textbf{64-Slice} & & & & \\
\hline
Per Segment & 88\% & 96\% & 79\% & 98\% \\
(n = 10,388) & (86\%-89\%) & (94\%-97\%) & (77\%-81\%) & (98\%-98\%) \\
\hline
Per Patient & 97\% & 90\% & 93\% & 96\% \\
(n = 695) & (95\%-98\%) & (86\%-93\%) & (91\%-96\%) & (92\%-98\%) \\
\hline
\end{tabular}
\end{table}

CCTA, cardiac computed tomographic angiography; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

Reprinted with permission from Hamon M et al.\textsuperscript{7}
multicenter study performed at 9 hospitals in 7 countries and in 291 patients, assessed the accuracy of 64-slice CCTA in symptomatic patients age 40 years or older who were referred for diagnostic CC. Patients with a body mass index greater than 40 or a calcium score at or exceeding 600 were excluded. The prevalence of at least 1 obstructive lesion was high, at 56%. The visual, per-patient sensitivity, specificity, PPV, and NPV were 83%, 91%, 92%, and 81%, respectively. The visual, per-vessel accuracy data were as follows: For 3-vessel disease, the sensitivity was 75%, the specificity was 93%, the PPV was 83%, and the NPV was 89%. The left main (LM), left circumflex (LCX), and right coronary artery (RCA) disease accuracy data were as follows: for LM, 80% sensitivity, 81% specificity, 81% PPV, and 88% NPV; for LCX, 73% sensitivity, 94% specificity, 82% PPV, and 90% NPV; and for RCA, 71% sensitivity, 95% specificity, 84% PPV, and 90% NPV. The higher prevalence of disease in this study may explain the lower NPV.

Most recently, Meijboom and colleagues18 published a multicenter, prospective study also using 64-slice CCTA in 433 symptomatic patients. The prevalence of at least 1 significant stenosis (≥ 50%) in this population was also high, at 68%. Nearly all (99%) patients who had significant CAD by CC were identified. In all patients with LM or 3-vessel disease, CCTA detected at least 1 significant stenosis, resulting in the correct clinical decision. However, 41 of 433 patients (9.4%) were incorrectly identified as having significant CAD.

On a per-patient basis, the sensitivity, specificity, PPV, and NPV in the study by Meijboom and colleagues18 were 99%, 64%, 86%, and 97%, respectively. The per-vessel and per-segment were 95% and 88% for sensitivity, 77% and 90% for specificity, 59% and 47% for PPV, and 98% and 99% for NPV. Stenosis severity was often overestimated in this study compared with conventional angiography. This can be explained by the inability of conventional coronary angiography (as just a “luminogram”) to take into account the positive vascular remodeling that occurs in atherosclerosis. The per-patient evaluations were accurate and robust when compared with coronary angiography.

Large studies evaluating the accuracy of 256-slice and 320-slice scanners have not been published because these newer scanners have not yet been put into broad commercial use.

The preponderance of evidence to date concerning the accuracy of CCTA in evaluating native coronary arteries in symptomatic patients supports the power of CCTA in ruling out disease. The NPV is generally 95% or greater in low- to intermediate-risk chest pain populations and, thus, CCTA is most appropriate in this patient subset. Although the accuracy of CCTA in identifying 3-vessel disease and all significant lesions is modest, the accurate identification of any significant disease on a per-patient basis is powerful. It may be argued that the per-patient evaluation is the most clinically important because it will result in necessary CC (and avoidance of unnecessary CC).

Furthermore, the accuracy of CCTA must be interpreted in the context of the prevalence of disease. NPV will be much lower and PPV much higher in patients with high prevalence of disease, whereas NPV is higher and PPV is lower in patient populations with low prevalence of disease. This concept may explain the varying NPV among these 3 prospective CCTA trials (Figure 4).

The most appropriate patient for a CCTA-guided approach to the evaluation of chest pain is the symptomatic patient at low to intermediate risk. At this time, existing data and the published appropriateness criteria16 do not support the use of CCTA in high-risk, symptomatic patients who may be best suited for CC, nor do they support CCTA as a screening test for patients in whom the benefits...
of CCTA may not justify the risks of radiation exposure and iodinated contrast administration. Future investigation is required before CCTA can be routinely recommended in these patient types.

**Coronary Bypass Grafts**

A meta-analysis of 16-slice CCTA versus 64-slice CCTA for coronary artery bypass patients has also been performed, which involved 15 studies and 723 patients.19,20 Graft assessability (including the distal anastomoses) varied between 78% and 100%. The pooled sensitivity, specificity, PPV, and NPV in 2023 grafts for significant stenoses and for occlusion were as follows: a sensitivity of 97.6% (95% confidence interval [CI], 96%-98.6%), a specificity of 96.7% (95% CI, 95.6%-97.5%), a PPV of 92.7% (95% CI, 90.5%-94.6%), and an NPV of 98.9% (95% CI, 98.2%-99.4%).

CCTA in bypass patients performs very well when it is used to analyze the body of a bypass graft. Bypass grafts are generally larger caliber vessels (not subject to the limits of spatial resolution), and the bodies of bypass grafts do not demonstrate significant motion artifact. However, a word of caution is appropriate. Although it is important to accurately visualize the body of bypass grafts, it is equally important to clearly evaluate the anastomotic sites and the native, unprotected coronary arteries because clinically significant stenoses may reside in these locations as well. Yet, bypass anastomoses and native un bypassed coronary arteries are often more difficult to assess due to clips that may surround the anastomotic site and due to the more advanced, calcified atherosclerotic disease often present in the native vessels of bypassed patients. Thus, it is wise to use caution and clinical selectivity when choosing CCTA to evaluate coronary artery bypass graft patients.

**Intracoronary Stents**

Reports on coronary stent analysis with CCTA have been published as well. A meta-analysis by Hamon and colleagues20,21 which included 15 studies and 1175 stents using 16-slice CCTA or higher, reports that 13% of all stents were unassessable. The sensitivity for the stent analysis was 84% (95% CI, 77%-89%), the specificity was 91% (95% CI, 89%-93%), the positive likelihood ratio (PLR) was 12.22 (95% CI, 6.6-22.6), and the negative likelihood ratio (NLR) was 0.23 (95% CI, 0.17-0.31). For a test to be useful, generally accepted values for PLR and NLR are greater than 10 and less than 0.1, respectively.21

Abdulla and colleagues22 published a meta-analysis on stent evaluation (270 intracoronary stents) in studies using only 64-detector CCTA. The accuracy of CCTA was as follows: a sensitivity of 80% (95% CI, 70%-88.5%), a specificity of 95% (95% CI, 92%-97%), a PPV of 80%, and an NPV of 95%. A more recent meta-analysis by Vanhoenacker and colleagues23 reviewed 14 studies that used 16-slice or higher scanners in 400 patients and 1039 stents. The pooled sensitivity and specificity were 82% (95% CI, 72%-89%) and 91% (95% CI, 83%-96%), respectively. The PLR was 9.34 (95% CI, 4.68-18.62), and the NLR was 0.2 (95% CI, 0.13-0.32). The most important factor in determining the likelihood of diagnostic stent imaging was a stent diameter of 3 mm or greater.21,24

At this time, it is not advisable to routinely use CCTA for the sole purpose of intracoronary stent evaluation. The blooming artifact resulting from the stent struts will often preclude accurate in-stent luminal imaging. Presently, CCTA cannot reliably be counted on to determine patency and restenosis in stents smaller than 3.0 mm. Even in stents larger than 3.0 mm, visualization of the stent lumen is not guaranteed. Furthermore, it takes significantly more time and effort to reconstruct and analyze CCTA data for stents than for nonstented coronary segments. Thus, CCTA for stent imaging may be more appropriately performed in centers committed to cardiovascular imaging rather than in general CT imaging practices. Presently, CC remains the test of choice to evaluate in-stent restenosis. Reliable intracoronary stent imaging will depend on changes in stent design, improvements in CCTA spatial resolution, and, possibly, on the further development of dual-energy CCTA.

The Future

In the last few years, rapid advances in CCTA technology have been observed that may ultimately prove to increase the diagnostic accuracy of CCTA. The Aquilion One 320-slice scanner (Toshiba America Medical Systems, Inc., Tustin, CA) provides an unprecedented 160 mm coverage with 1 single 350 ms gantry rotation, virtually eliminating misregistration artifacts. The Brilliance ICT 256-slice scanner (Phillips Healthcare, Andover, MA) provides 80 mm of coverage with a gantry rotation of 270 ms. Air-bearing technology was used to allow this improved temporal resolution (potentially allowing diagnostic imaging at higher heart rates).

The Discovery™ CT750 HD (GE Healthcare, Piscataway, NJ) uses a new Gemstone detector that is claimed to be 100 times more sensitive than the standard detector technology, resulting in improvements in spatial resolution, decreased calcium blooming artifact,
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Figure 5. A depiction of the annual mortality rate determined by CCTA category in red and by percent of myocardial ischemia demonstrated in green. CCTA categories are as follows: 0, < 50% stenosis in 1 artery; 1, 30% to 49% stenosis with proximal disease in 1 artery or 1 stenosis of 50% to 69%; 2, 2 stenoses of 50% to 69% or 1 vessel of ≥ 70%; 3, 3 stenoses of 50% to 69% or 2 vessels of ≥ 70% or ≥ 70% in the proximal left anterior descending artery stenosis; 4, 3 vessels of ≥ 70% stenosis or 2 vessels of ≥ 70% stenosis with 1 stenosis in the proximal left anterior descending artery; 5, 50% to 69% left main stenosis; 6, ≥ 70% left main stenosis. Comparison of risk categories by CCTA versus percent of myocardial ischemia demonstrated a P value of .33, indicating no significant difference. CCTA, cardiac computed tomographic angiography; CAD, coronary artery disease. Adapted with permission from Shaw LJ et al.29

and, perhaps, the ability to successfully image smaller stents. Most recently, the SOMATOM Definition Flash (Siemens, New York, NY) uses dual-source 128 detector technology with a vendor-reported high-temporal resolution and coronary imaging at less than 1 mSv. Vendors have also reported radiation doses of below 10 mSv for combined perfusion and coronary imaging. Large, prospective studies are needed to confirm the potential benefits of these new technologies.

Prognostic Data
Although CCTA has not been shown to reliably predict ischemia,25-27 its role as a prognosticator is emerging. The power of SPECT to predict cardiac events is well documented.28 By comparing CCTA to SPECT, Shaw and colleagues29 first identified the prognostic power of CCTA. They noted similar annual, risk-adjusted mortality rates in patients with varying degrees of CAD identified by CCTA as in those patients with varying degrees of ischemia detected by SPECT (Figure 5).

To date, 2 other important CCTA prognostic studies have also been published. Pundziute and colleagues30 prospectively followed 104 consecutive patients presenting to the outpatient clinic with suspected CAD. CCTA was performed in all patients. In a multivariate analysis, coronary plaques, obstructive CAD, LM, and left anterior descending disease, number of coronary segments with obstructive plaques, and number of coronary segments with mixed plaques were independent predictors of cardiac events, driven mainly by revascularization. No events occurred in patients with no CAD versus 30% in patients with any CAD as detected by CCTA (P = .005).

In a larger study, Min and colleagues31 prospectively evaluated 1127 consecutive patients ages 45 years or older who presented with atypical chest pain. CCTA was the primary diagnostic imaging modality. CCTA scans were assessed for the number of vessels involved, for the Duke prognostic CAD index for CC32,33 as applied to CCTA, and for a novel coronary artery plaque score developed by the study authors to represent worsening extent of overall coronary artery plaque. In a multivariate analysis, the presence of plaque in increasing numbers of coronary arteries, moderate and severe plaque, and plaque in the LM were independent predictors of all-cause mortality. In addition, the Duke prognostic CAD index was a significant predictor of all-cause mortality (Figure 6).

These prognostic studies begin the next step toward clinical acceptance for CCTA by demonstrating the ability of CCTA to predict hard adverse cardiovascular outcomes. Certainly, more studies of this type are needed. Furthermore, additional studies are necessary to examine the role of CCTA in the context of other proven cardiovascular imaging modalities. In addition, it will be essential to validate the role of CCTA in clinical decision-making and in guiding cardiovascular disease management decisions.

A Rebuttal of the Criticism of CCTA
Much skepticism and criticism has surrounded the emergence of CCTA. Common criticisms include that CCTA is misused, overutilized, costly, and dangerous. Some editors34 and lay press publications34 ignore and oversimplify the data and thus create an incomplete or misleading picture. There may be concerns that CCTA will escalate healthcare costs and decrease private insurance payer profits.

The CCTA evaluation process and its progression to a mainstream cardiac imaging modality must be
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handled with unbiased hands. CCTA experts and clinicians should be commended for their responsibility and expertise in introducing and developing CCTA. Nearly 5000 physicians and ancillary medical professionals have joined the Society for Cardiovascular Computed Tomography, a society dedicated to CCTA education, research, and responsible utilization. Clinical training guidelines, a training course certification process, verification of physician training, a cardiovascular certification board, and appropriateness criteria for the use of CCTA were proactively created to ensure proper training, study, and application of this modality.

CCTA is frequently criticized for its significant radiation exposure, with claims that the radiation exposure with CCTA is severalfold higher than alternative coronary artery evaluation methods. To the contrary, CCTA has raised awareness of the need for responsible diagnostic radiation use in all areas of patient care.

Findings of the Prospective Multi-center Study on Radiation Dose Estimates of Cardiac CT Angiography in Daily Practice I (PROTECTION 1) study (no industry sponsorship) demonstrated wide variations in radiation dose (5.7 mSv to 36.5 mSv) among participating sites. This observational study included 50 sites worldwide and 1965 CCTA examinations performed during 1 month. Higher radiation doses were often found to result from a failure to use available dose-saving techniques that are often simple to add to institutional imaging protocols.

Technological advances and patient-specific CCTA protocols have led to marked reductions in CCTA radiation exposure. Dose modulation techniques available on all scanners have been shown to reduce effective doses by nearly 50%. Reductions in radiation energy in thinner patients have also been shown to substantially reduce the radiation dose. X-ray energy settings may be modified on all scanners. In addition, prospective imaging has reduced the CCTA radiation dose from 17.2 mSv to 3.1 mSv without compromising image quality. These newer CCTA protocols result in effective doses of radiation that approach those of CC (4-10 mSv).

As a comparison, the effective doses for standard chest CT, high-resolution chest CT, abdominal CT, and pelvic CT are 6 to 7 mSv, 1 mSv, 13 mSv, and 12 mSv, respectively.

It is surprising that radiation exposure from CCTA has attracted so much attention because nuclear stress testing is ordered much more frequently and is associated with much higher average effective doses (14 to 24 mSv). Furthermore,
frequently used dual-isotope protocols expose patients to average doses near 27 mSv. CCTA critics have not properly noted these data.

In addition, the claim of an estimated 2% excess risk of cancer from a single CCTA scan is clearly an overestimate because CCTA administers radiation in a controlled setting to the chest with a focus on the heart. This excess risk assumption for CCTA is based on the cancer rates of atomic bomb survivors who received effective doses of 5 to 20 mSv. It is biologically incorrect to compare the radiation exposure from 1 single CCTA to that experienced by an atomic bomb survivor.

It must also be noted that the risk of radiation-induced malignancy depends strongly on the patient’s age at the time of exposure. Exposure at earlier ages increases future cancer risk. Most patients undergoing CCTA are in their fifth and sixth decades, and thus their excess risk is comparatively low. In fact, the estimated risk of future neoplasm (using older CCTA protocols) for a 60-year-old woman and a 60-year-old man are approximately 0.14% and 0.05%, respectively. In addition, it may be argued that the risk of the morbidity and mortality that results from a failure to diagnose CAD at an early stage may be much higher than that of the radiation dose used to make this diagnosis.

Unnecessary radiation exposure from CCTA may be avoided by appropriate patient selection. At this time, CCTA is not appropriate as a screening test for asymptomatic individuals. Choi and colleagues studied 1000 asymptomatic, middle-aged (≤ 50 years) patients who were self-referred for CCTA. They demonstrated that very few had any plaque (22%). Only 5% had a 50% or greater stenosis, and remarkably few (2%) had a 75% or greater stenosis. Only 15 cardiac events occurred in this study (1 unstable angina event and 14 coronary revascularizations). There were no observed myocardial infarctions or deaths, and no events were documented in patients shown to have no plaque. Thus, the risk-benefit ratio of CCTA in the asymptomatic patient does not justify its utilization in this population. Calcium scoring alone (1-2 mSV) may be a more appropriate screening test.

Claims of CCTA misuse, overutilization, and increased expense are not supported by a comparison of the 2007 Medicare carrier claims summary file to that of the 2006 claims summary obtained from the Center for Medicare and Medicaid Services. Remarkably, in 2006 or 2007, CCTA did not make the list, which indicates that less than $50 million was spent on this modality. CCTA is included in the “heart image (3d), multiple” category. In 2007, $1.07 billion was spent on this broad category of advanced heart imaging versus $1.16 billion in 2006, a decline of $90 million.

In addition, Medicare spending for advanced heart imaging, echocardiography, and stress testing declined by at least $1.2 billion in 2007, whereas spending on CC was nearly $3.3 million less than in 2006. These data do not support overuse or misuse of CCTA and do not suggest excessive layering of diagnostic imaging tests when a CCTA-guided approach is used. Nor do these data confirm an increase in spending on cardiovascular imaging since the introduction of CCTA.

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Unnecessary radiation exposure from CCTA may be avoided by appropriate patient selection. At this time, CCTA is not appropriate as a screening test for asymptomatic individuals. Choi and colleagues studied 1000 asymptomatic, middle-aged (≤ 50 years) patients who were self-referred for CCTA. They demonstrated that very few had any plaque (22%). Only 5% had a 50% or greater stenosis, and remarkably few (2%) had a 75% or greater stenosis. Only 15 cardiac events occurred in this study (1 unstable angina event and 14 coronary revascularizations). There were no observed myocardial infarctions or deaths, and no events were documented in patients shown to have no plaque. Thus, the risk-benefit ratio of CCTA in the asymptomatic patient does not justify its utilization in this population. Calcium scoring alone (1-2 mSV) may be a more appropriate screening test.

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Cardiac CT Angiography continued

be judged fairly. Data currently support its use for the diagnosis and prognosis of CAD in low- to intermediate-risk patients with chest pain.

Questions regarding the ability of CCTA to prolong life or improve quality of life are unfair and unrealistic. No diagnostic imaging test has been held to this standard. Furthermore, rigidly comparing CCTA to CC is a flawed scientific analysis. These are independent and complementary tests with different strengths and weaknesses that are used for different purposes. CCTA should not be considered a potential replacement for CC.

Although the more powerful spatial resolution of CC allows for more accurate grading of coronary stenoses and is not limited by the blooming artifact of coronary calcification, CC without intravascular ultrasound (IVUS) is unable to visualize the actual vessel wall and is merely a “lumen-gram.” Furthermore, IVUS is not routinely possible, available, or practical. On the contrary, CCTA may be better able to diagnose atherosclerosis not evident on CC. This strength may in fact add value to patient care by allowing earlier diagnosis and treatment. This claim requires future study.

An important future study to answer remaining critical questions regarding CCTA is in the planning stages. The Functional or Anatomic or Both Functional and Anatomic Testing in Symptomatic Individuals Undergoing Evaluation by CCTA, MPS, or Both: Costs and Clinical Outcomes (FABULOUS) trial is a multicenter, randomized study that will evaluate the clinical utility and cost-effectiveness of an anatomic imaging strategy using CCTA versus a functional imaging strategy using myocardial perfusion imaging in patients without known CAD who present with stable chest pain syndromes.

Conclusion

At present, CCTA may uniquely identify otherwise clinically silent atherosclerosis. In addition, because CCTA may rule in or rule out a plethora of other cardiovascular and noncardiovascular diagnoses, and because stress SPECT imaging has limited ability to diagnose functionally insignificant CAD and other noncardiac ailments, an argument may be made to use CCTA as a first test in the evaluation of chest pain in the low- to intermediate-risk patient (Figure 7).

Figure 7. A proposed clinical practice CCTA integration algorithm for low- to intermediate-risk patients with chest pain. CCTA, cardiac computed tomographic angiography; CV, cardiovascular; Rx, prescription.
Cardiac CT Angiography

Main Points

• Advances in cardiac computed tomographic angiography (CCTA) result in reproducible and accurate images of the coronary arteries.

• The power of CCTA lies in its negative predictive value, or its ability to rule out disease.

• The performance of CCTA improves with 64-slice CCTA when compared with 16-slice CCTA, especially with regard to sensitivity.

• CCTA in bypass patients performs very well when it is used to analyze the body of a bypass graft.

• At this time, it is not advisable to routinely use CCTA for the sole purpose of intracoronary stent evaluation.

• Technological advances and patient-specific CCTA protocols have led to marked reductions in CCTA radiation exposure.

References


Guidelines

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

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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 scan performance 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.

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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.1

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 extracardiac 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,2 or the ACR Practice Guideline for the Performance and Interpretation of Cardiac Computed Tomography3), 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 β-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 × 2 or 64 × 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 β-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. Furthermore, small amounts of absorbed iodine from the contrast material may affect the fetus’ thyroid function. 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.

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 β-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.”
   b. Contraindication to contrast media or other medications including β-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 β-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, 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.
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.

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. 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.

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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. 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%, and in a study of 400 patients with renal insufficiency undergoing MDCT and receiving CIN-preventive measures, the incidence of CIN was < 2%. 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). The use of N-acetylcysteine or bicarbonate may be considered, but available data are not sufficient to make recommendations.

3.7. Preprocedure medications and instructions

3.7.1. β-Blockade

Most current-generation MDCT scanners require both a slow heart rate and a regular cardiac rhythm for optimal image quality. 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. β-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 β-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. 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 β-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 β-blockers in the setting of known or suspected sick sinus syndrome, unexplained presyncope or collapse, current use of other antiarhythmic 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 β-blockers.

A 12-lead electrocardiogram (ECG) before administration of β-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. A commonly used regimen is 400–800 μg (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, tadalafil) or is taking sildenafil for pulmonary hypertension. Use is also contraindicated in those clinical states in which systemic vasodilatation 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, GFR < 60mL/min/m²), 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.
- β-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 β-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 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. 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. 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. 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. 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.

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.35 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.36 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.37 Furthermore, it is assumed that there is no safe amount of radiation and that any radiation exposure is potentially harmful.38 Available data suggest that particularly children and young adults are at risk from radiation exposure.39 The harmful effect is cumulative, i.e., 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.40 Because of higher sensitivity of breast tissue to radiation, radiation risks of coronary CTA are higher for women than for men.41

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 (e.g., 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 (i.e., 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.42

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.43 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.44,45 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/m².

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 (i.e., 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.46

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.44 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.44 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.47 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.42 Preliminary experience with prospectively triggered coronary CTA suggests that diagnostic studies can be obtained with as little as 1–3 mSv.48,49 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. Extrapolating from experience with chest CT, radiation exposure to organs outside the scan field during cardiac CT is negligible, not warranting shielding. 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).

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/slide 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. 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. 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 CTA 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. At the same time, more extensive coronary calcification increases the likelihood that the patient has
obstructive coronary artery disease. According to some centers, the presence of a coronary calcium score exceeding 600–1000 is considered 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. 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.

### 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.

### 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 < 30 kg/m².
- 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 are 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 × 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. 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.

### 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. 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. 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. 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. Importantly, even a slight shift of this timeframe of as little at 50 milliseconds away from the optimal timeframe can create artifacts that mimic coronary stenosis. 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 multidetector 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. 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. \(^\text{75}\)

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**


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52. Hausleiter J, Meyer T, Hadamitzky M, Jiang C, Hendrich E, Hausleiter J: Reduction of radiation dose estimates in car-


Guidelines

SCCT guidelines for the interpretation and reporting of coronary computed tomographic angiography

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Cardiovascular computed tomography; Computed tomography; Contrast angiography; Coronary artery; Guidelines

Part A: Interpreting coronary computed tomographic angiograms

Preamble

The increasing use of coronary computed tomography angiography (CCTA) 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 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 CCTA based on the best available data or broad expert consensus. Due to 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.

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 members and Writing Group members are published

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in the appendices of these documents. These are reviewed by the Guidelines Committee and will be updated as changes occur.

Introduction

Comparison of coronary CTA to invasive coronary angiography

CCTA has important similarities to and differences from invasive coronary angiography (ICA). Decades of research into the prognostic implications of ICA findings provide a solid basis for classification of the coronary tree and description of stenosis severity in CCTA.1–4 In these instances, established ICA standards have been used with minimal alteration. However, CCTA may also provide information about the presence of extra-luminal plaque and plaque composition that is not routinely available on ICA without the use of intravascular ultrasound.5–9 The CCTA data set also contains non-coronary cardiac and extra-cardiac thoracic information of importance,10–21 including myocardial, pericardial, and valvular morphology and function as well as aortic and pulmonary vascular structural detail. Thus, cardiac CTA shares elements in common with echocardiography and thoracic radiology in addition to ICA. Interpreting such a wide breadth of information demands a systematic approach, one that enforces attention to all anatomical structures and to the full potential of this technology.

Limitations of this document

In addition to its use for anatomic evaluation of the coronary arteries, computed tomography of the cardiovascular system is broadly applicable to congenital heart disease; myocardial, pericardial, and valvular heart disease; and diseases of the thoracic and peripheral arteries and veins. Clearly, a single Guideline covering this wide a spectrum would not be practically useful.

For this reason, these Guidelines are focused on CCTA. However, an approach to interpreting and reporting of common non-coronary cardiac and extra-cardiac thoracic pathology that may occur within the cardiac field of view is discussed briefly, to facilitate a more systematic and inclusive approach to interpreting and reporting the CCTA examination.

Qualifications of interpreting physicians

Reliable interpretation of coronary angiography by computed tomography requires a sophisticated understanding of (1) normal coronary and cardiac anatomy; (2) the pathophysiology of coronary atherosclerosis and other abnormalities, including congenital anomalies; (3) the characteristic appearance of coronary artery and cardiac lesions on computed tomography with and without contrast; (4) the technology and limitations of computed tomography; (5) the use of a 3-dimensional workstation; and (6) the ability to identify and overcome flaws in the available image data set. The development and integration of these skills requires capable instruction as well as significant experience.22,23 The currently recommended training process to attain competency in interpretation has been outlined in previous medical specialty society statements.24,25 In addition to these specialty-specific requirements, it is highly recommended that, in the United States, CCTA interpreters achieve certification by examination through the Certification Board of Cardiovascular Computed Tomography, or by subspecialty examinations in this discipline provided through American Board of Medical Specialty societies26 or international subspecialty boards, if these become available at a future date.

Underlying principles of interpreting CCTA studies

Three-dimensional data sets and workstations

Coronary computed tomography images should be acquired as isotropic sub-millimeter 3-dimensional electrocardiogram (EKG)–gated data sets, which facilitate reconstruction and display in a variety of image formats.27,28 Because of the complexity of coronary anatomy, the frequency of motion and calcium-related image artifacts, and the morphologic subtleties of lesions, interpreters must review CCTA interactively on workstations capable of 2- and 3-dimensional displays in all conventional reconstruction formats. These include transaxial 2-dimensional image stacks (“raw data”), multiplanar reformatations (MPRs), maximum intensity projections (MIPs), curved multiplanar reformations (cMPRs), and volume-rendering technique (VRT) reconstructions. Images are most often generated from data that may be acquired either in retrospectively gated helical mode or prospectively triggered sequential mode. In many cases with heart rate–related artifacts, diagnostic quality may be improved by additional image reconstructions at alternate times in the cardiac cycle with reduced cardiac motion.29–33 For this reason, skilled interpretation requires that the reading physician be trained in the recognition of correctable artifacts and be familiar with the acquisition and reconstruction process.34 Because of the potential need for additional reconstructions, raw data files must be retained until image interpretation is complete.

Interpretation formats

Transaxial images (“raw data”)

Transaxial images are the basic imaging result of the scanning and reconstruction process and consist of a series of 2-dimensional images stacked in the longitudinal (cranial-caudal or z-axis) direction in which they were acquired. These are examined directly by scrolling through the image slices but only from the straight caudal-cranial perspective. A major advantage of this format is that the
image information content displays the minimum likelihood of distortion or errors consequent to post-processing and the maximum resolution and gray-scale rendering.\textsuperscript{35,36} A disadvantage of this format is that it requires the reader to mentally reconstruct the 3-dimensional anatomic relationships of the arteries and other structures in the thorax, since the data are displayed in 2 dimensions and from one point of view. In addition, when viewing transaxial images the thickness of each slice is determined by the reconstruction width and is not variable, so tortuous arteries will move in and out of plane, requiring more skill from the interpreter to follow the course of a given vessel. Properly setting the window level and window width is critical for accurate interpretation in order to differentiate contrast-containing lumen from calcified plaque and to preserve the gray-scale subtlety needed to distinguish intramural non-calcified plaque from interstitium.\textsuperscript{37–39} In general, the window level should be at the mean of the Hounsfield unit values within the region of interest, while the window width should be about 2.5 times the level. In standard examinations done at 120 kVp an initial window width of 800 and a level of 300 is a useful starting point, but the interpreter should make readjustments for body habitus, extent of calcification, and contrast intensity.

**Multi-planar reformation (MPR)**

MPR is an alternative high-resolution reconstruction format that allows display of planar images at any angular section through the acquisition volume, which permits visualization in not only the axial plane but also in orthogonal (coronal and sagittal) or oblique planes that better follow the arterial course in the thorax. In addition, arbitrary planes intersecting the volume at favorable angles, such as right anterior oblique with cranial angulation, can reproduce familiar invasive angiographic views. Most workstations will allow interpreters to simultaneously scroll through views of three orthogonal oblique MPRs. In addition, it is easy to rotate the vessel on its longitudinal axis through 360 degrees, or page through transverse MPRs through the vessel. These maneuvers are useful in delineating the morphology of plaque and its effect on the lumen and adjacent vessel wall.\textsuperscript{32,36} In general, the smallest available slice width is used in MPRs to optimize image quality, unless signal-to-noise requires an increase in slice width to preserve interpretability.

Curved multiplanar reformation (cMPR) format was developed to allow the interpreter to follow the course of a tortuous vessel for longer distances as it changes direction.\textsuperscript{30,41} This requires that the centerline of the vessel be tracked correctly, which can be done manually or automatically. While cMPR has the advantage of producing a view of the entire course of the vessel in one image, it has a potential serious downside in that inaccurate centerline tracking may cause artifactual lesions. When using cMPR, the interpreter should review the centerline for accuracy.

**Maximum intensity projection (MIP)**

MIP is similar to MPR in that orthogonal or oblique planes can be reviewed interactively.\textsuperscript{41,42} They differ in that, generally, MIP is created in thicker sections, chosen to incorporate a volume that includes the entire vessel lumen and wall diameter (commonly 5 mm as an initial thickness for coronary interpretation), and that each pixel is represented by the maximum pixel value within the slab volume.\textsuperscript{37} These features allow the reader to visualize a longer segment of a vessel’s course and tend to reduce perceived image noise. However, there is loss of lesion information within the slab volume, as the MIP does not provide in-depth information or attenuation detail within the slice.\textsuperscript{43} Consequently, MIP should not be the sole technique used for interpretation. Since modern workstations allow switching back and forth between formats without a position change, toggling between MIP and MPR captures the advantages of both when reading a particular vessel segment.

**Volume-rendering technique (VRT)**

Another technique in common use is VRT, which creates volumetric 3-dimensional representations with the illusion of spatial integrity and color. It is generally not useful for the assessment of coronary stenosis since the apparent thickness of the vessel lumen is dependent on window settings and the computer algorithm that is used to subtract non-vascular structures.\textsuperscript{41} VRTs are useful for visualizing spatial relationships, such as defining the course of coronary anomalies and the presence and course of coronary bypass grafts. This technique finds much more use in the analysis of thoracic cardiovascular anatomy, in congenital heart disease, and for teaching purposes and illustrations for patients.

The following tables (Table 1 and Table 2) summarize key underlying principles of interpreting coronary CTA.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Underlying principles of CTA interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpretation should be made on 3-dimensional workstations equipped to display recommended image reconstruction formats.</td>
<td></td>
</tr>
<tr>
<td>Images should be reviewed in the appropriate post-processing formats. (See Table 2)</td>
<td></td>
</tr>
<tr>
<td>Interpreters should be prepared to customize image reconstructions if necessary.</td>
<td></td>
</tr>
<tr>
<td>The data set should be previewed for artifacts.</td>
<td></td>
</tr>
<tr>
<td>Non-contrast studies should be reviewed prior to contrast studies.</td>
<td></td>
</tr>
<tr>
<td>The coronary tree should be examined systematically.</td>
<td></td>
</tr>
<tr>
<td>Lesions should be reviewed in multiple planes and conceptualized in 3-dimensions.</td>
<td></td>
</tr>
<tr>
<td>Lesions should be assessed for extent and quality of plaque, not just for stenosis severity.</td>
<td></td>
</tr>
<tr>
<td>Extra-coronary cardiac and thoracic anatomy should be examined within the cardiac field of view.</td>
<td></td>
</tr>
</tbody>
</table>
Non-contrast coronary interpretation: coronary calcium scoring

A preliminary non-contrast examination for coronary artery and other cardiac structural calcification is routine in many centers and is frequently used in centers where it is considered optional, but is not mandatory in every case. Use of prospective triggering further reduces radiation with the calcium score, and the increase in radiation exposure (generally 0.5–1.5 mSv) must be weighed against the value of additional quantifiable information gained. The non-contrast examination requires independent interpretation and reporting and should include examination of the entire cardiac field, including valves and pericardial surfaces. Calcium scoring computer programs generally identify pixels that exceed 130 Hounsfield units as a level corresponding to calcium on a non-contrast study.44,45 The reader needs to identify each lesion (discrete calcific focus) in each vessel distribution (right coronary artery, circumflex, left main, and left anterior descending arteries). The summed score for each vessel is generated by the scoring program based on either an area-density (Agatston score)44 or volumetric46 measurement of each calcified focus. The mass score is less commonly used in clinical practice.47–49 Since there is no current validation data for this measure (no normograms, outcome studies, histology studies, etc), the use of mass score should be accompanied by reporting of the more traditional (and clinically understood) Agatston score. The total coronary calcium score is the sum of all calcific lesions in all coronary beds. Excluded from the total coronary calcium score is calcium in the aorta, aortic valve, mitral annulus or valve, and pericardium or myocardium.

Reporting of the calcium score is somewhat dependent on reader preference, but, at the minimum, a calcium score (using either Agatston or optionally Volumetric scoring algorithm) for each vessel and a total calcium score should be reported. Also, calcium in the other portions of the heart should be noted (but not quantified). Aortic valve, mitral annulus, and aortic wall can be semi-quantified (mild, moderate, severe calcification) as a preferred but optional reporting method, as these measures may have independent prognostic and diagnostic value.

Table 2  Recommended image post-processing formats

<table>
<thead>
<tr>
<th>Post-processing format</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial image review</td>
<td>Recommended</td>
</tr>
<tr>
<td>Multiplanar reformation (MPR) image review</td>
<td>Recommended</td>
</tr>
<tr>
<td>Maximum intensity projection (MIP) image review</td>
<td>Recommended</td>
</tr>
<tr>
<td>Curved multiplanar reformation (cMPR) image review</td>
<td>Optional</td>
</tr>
<tr>
<td>Volume-rendered reconstructions</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

Table 3  Required and optional reporting on coronary calcium non-contrast CT

<table>
<thead>
<tr>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agatston score for each vessel</td>
</tr>
<tr>
<td>Agatston score for total study (sum of 4 vessels)</td>
</tr>
<tr>
<td>Presence of calcium in aortic wall, aortic valve, mitral annulus/valve, pericardium, and myocardium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Further delineation of calcium score by branches (posterior descending, diagonals)</td>
</tr>
<tr>
<td>Number of lesions: per vessel and total</td>
</tr>
<tr>
<td>Volumetric or mass score: per vessel and total</td>
</tr>
<tr>
<td>Aortic valve calcium score</td>
</tr>
<tr>
<td>Aortic wall calcium score</td>
</tr>
<tr>
<td>Mitral annular calcium score</td>
</tr>
<tr>
<td>Dilated chambers or total heart enlargement</td>
</tr>
<tr>
<td>Pericardial effusions/thickening/pericardial fat</td>
</tr>
<tr>
<td>Non-cardiac structures (pleural effusions, pulmonary nodules, mediastinal abnormalities, etc)</td>
</tr>
</tbody>
</table>

Table 3 summarizes the required and optional reporting elements for a coronary calcium non-contrast CT report.

Coronary artery angiography interpretation

Examination of image quality

Because of the constant motion of the heart and the intrinsic limitations of computed tomography, artifacts due to motion, calcification, and metallic densities; image noise; and poor contrast enhancement all may degrade the quality of the study as well as simulate or obscure coronary stenoses.50–52 This is sufficiently common to require identification of artifacts prior to definitive image interpretation.

Reconstruction artifacts

“Stairstep artifacts” are due to motion occurring between reconstruction of sequential heartbeats. This motion can be due to breathing, gross body motion, or irregularity of heart rate causing gating at different points in the cardiac cycle. As a consequence, anatomy in the longitudinal direction may abruptly shift mid-vessel and emulate a vessel stenosis, particularly in the axial view. Coronal and sagittal planes are perpendicular to the table travel and make these more obvious. Customized reconstructions at a different cardiac phase may be successful by either adjusting the phase of reconstruction or removing data from undesirable beats (such as premature contractions). Artifacts due to breathing or body motion are distinctive because they affect the bones of the anterior or lateral chest wall in addition to the coronary arteries; these are less likely to be correctable by additional reconstructions. Motion occurring within a single
heartbeat reconstruction will cause blurring of the vessel and may be correctable by alternative reconstructions.

**Metal and calcific density artifacts**

Metal density artifacts include beam-hardening, blooming, and streaking. Dark beam-hardening artifacts may simulate a non-calcified plaque in proximity to calcifications, and blooming artifacts commonly make calcified plaque and stents appear to narrow the lumen more than they actually do.

**Reduced signal-to-noise and low vessel contrast intensity**

Image quality may be impaired by poor signal-to-noise, which can be due to obesity, improper scan parameters (low tube output for a given body size), or reconstruction during a part of the cardiac cycle with reduced tube current from EKG-guided tube modulation. Low contrast intensity may be secondary to improper image acquisition timing or slow contrast injection.

**Coronary artery interpretation**

The guiding principles of interpretation include (1) systematic review of each coronary segment from multiple planes and in transverse section, (2) awareness of relevant artifacts, (3) evaluation of lesion morphology and composition, and (4) assessment of stenosis severity using high-resolution images (including MPR format) in views both longitudinal and transverse to the vessel. An image review in the frontal and lateral planes may aid in the identification of artifacts. Many experienced readers will review the arterial tree in detail beginning in the axial (caudal) view since the trans-axial data are more robust as are the less processed.

**Coronary segmentation**

A standardized approach to coronary segmentation improves description and communication of findings. The standard American Heart Association (AHA) segmentation initially proposed in 1975 has stood the test of time and has been used in many long-term outcome studies relating the location of stenoses to major adverse coronary events. This model has been adapted for CCTA with minimal alterations for clarity. An axially based version of this standard model is displayed in Figure 1, which has been altered to more closely emulate CTA views than the standard views obtained during ICA that were used in the original publication. In addition to combining the 3 standard invasive angiographic views into a single axial view, this model varies from the 1975 standard AHA segmentation in the following ways: a left posterolateral branch is identified as segment 18, and a ramus intermedius branch has been added as segment 17. An optional alternative segmentation model is the 28 segment model that was used in the Myocardial Infarction and Mortality in Coronary Artery Surgery Study (CASS)\(^3\) (see Table 4).

**Analysis of coronary artery anatomy and pathology**

The coronary tree should be initially examined for the course and branching of the main coronary vessels and subbranches. Coronary anomalies should be examined with regard to their origin, course, and relationship to important structures such as the cardiac chambers, aorta, pulmonary artery, and interventricular septum.

The lumen of the coronary arteries should be examined for overall caliber and smoothness. Variations in CT density within the mural and intraluminal portions of the coronary artery should be noted and compared with the adjacent interstitium, contrast-containing lumen, and calcific densities such as bone or calcified plaque. Atherosclerotic lesions should be considered in relationship to their segmental position due to the affected extent of myocardium. The impact of luminal plaque should be evaluated in terms of the resultant maximal percentage of diameter stenosis and, optionally, percentage of area stenosis. Since CCTA can visualize intramural presence of positively re-modeled plaque and differentiate calcific, non-calcific, and mixed plaque, these attributes should also be examined and reported in segmental fashion. Description of plaques as "non-calcific" is preferable to "soft" or "lipid-rich" since low CT density (in Hounsfield units) levels do not necessarily correlate closely with anatomic pathology or biochemistry. It is recommended that features of plaque morphology such as ulceration, dissection, and fissuring be noted when image quality is sufficient. Optional additional plaque modifiers include "ostial," "branch," "long," and "positive remodeling." Non-atherosclerotic lesions such coronary aneurysms should stimulate investigation of other associated vascular pathology in the non-cardiac thoracic portion of the examination.

**Qualitative assessment of stenosis severity**

The ultimate objective of interpretation is to convey diagnostic information to the treating physician with as much clarity and accuracy as possible. This requires an understanding by the ordering physician and the CCTA reader of the strengths and limitations of CCTA as well as how it differs from invasive angiography’s luminal information and from functional tests that directly test myocardial perfusion or its effects. For example, intramural plaque may be visible without luminal stenosis, which would be Grade 1 in the qualitative and quantitative scales below. Also, interpretation may convey the reader’s expert opinion on the potential pathophysiological importance of a lesion. In addition, the reader should specifically state if an artery or artery segment is not interpretable and why. The

<table>
<thead>
<tr>
<th>Segment</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal RCA</td>
<td>pRCA</td>
<td>Ostium of the RCA (right coronary artery) to one-half the distance to the acute margin of heart</td>
</tr>
<tr>
<td>Mid RCA</td>
<td>mRCA</td>
<td>End of proximal RCA to the acute margin of heart</td>
</tr>
<tr>
<td>Distal RCA</td>
<td>dRCA</td>
<td>End of mid RCA to origin of the PDA (posterior descending artery)</td>
</tr>
<tr>
<td>PDA-RCA</td>
<td>R-PDA</td>
<td>PDA from RCA</td>
</tr>
<tr>
<td>PLB-RCA</td>
<td>R-PLB</td>
<td>PLB (posterior-lateral branch) from RCA</td>
</tr>
<tr>
<td>LM</td>
<td>LM</td>
<td>Ostium of LM (left main) to bifurcation of LAD (left anterior descending artery) and LCx (left circumflex artery)</td>
</tr>
<tr>
<td>Proximal LAD</td>
<td>pLAD</td>
<td>End of LM to the first large septal or D1(first diagonal), whichever is most proximal</td>
</tr>
<tr>
<td>Mid LAD</td>
<td>mLAD</td>
<td>End of proximal LAD to one-half the distance to the apex</td>
</tr>
<tr>
<td>Distal LAD</td>
<td>dLAD</td>
<td>End of mid LAD to end of LAD</td>
</tr>
<tr>
<td>Diagonal 1</td>
<td>D1</td>
<td>First diagonal branch D1</td>
</tr>
<tr>
<td>Diagonal 2</td>
<td>D2</td>
<td>Second diagonal branch D2</td>
</tr>
<tr>
<td>Proximal LCx</td>
<td>pCx</td>
<td>End of LM to the origin of the OM1 (first obtuse marginal)</td>
</tr>
<tr>
<td>OM1</td>
<td>OM1</td>
<td>First OM1 traversing the lateral wall of the left ventricle</td>
</tr>
<tr>
<td>Mid and distal LCx</td>
<td>LCx</td>
<td>Traveling in the AV groove, distal to the first obtuse marginal branch to the end of the vessel or origin of the L-PDA (left posterior descending artery)</td>
</tr>
<tr>
<td>OM2</td>
<td>OM2</td>
<td>Second marginal OM2</td>
</tr>
<tr>
<td>PDA-LCx</td>
<td>L-PDA</td>
<td>PDA from LCx</td>
</tr>
<tr>
<td>Ramus intermedium</td>
<td>RI</td>
<td>Vessel originating from the left main between the LAD and LCx in case of a trifurcation</td>
</tr>
<tr>
<td>PLB-L</td>
<td>L-PLB</td>
<td>PLB from LCx</td>
</tr>
</tbody>
</table>

Dashed lines represent division between RCA, LAD, and LCx and the end of the LMPLB = PLV (posterior left ventricular branch) Additional nomenclature may be added for example: D3, R-PDA2, SVG (saphenous vein graft) mLAD
Recommended Qualitative Stenosis Grading

0 Normal: Absence of plaque and no luminal stenosis
1 Minimal: Plaque with negligible impact on lumen
2 Mild: Plaque with no flow-limiting stenosis
3 Moderate: Plaque with possible flow-limiting disease
4 Severe: Plaque with probable flow-limiting disease
5 Occluded

Quantitative assessment of stenosis severity

Quantification of the luminal stenosis, area stenosis, and plaque extent is available using digital tools and may assist interpretation, but current technology has not demonstrated sufficient reproducibility or accuracy in predicting ICA findings to make such measurements a routine requirement. Studies have reported that CCTA quantification of lesion severity in terms of the percentage of maximal diameter stenosis has good general correlation with quantitative invasive angiography (QCA) and intravascular ultrasound, but with a relatively large standard deviation. These comparative studies suggest that, at a 95% confidence limit, CCTA currently predicts QCA to within ±25% at best. Although future technical developments may improve the precision of stenosis quantification, at the present time, it is recommended that arterial segments be described within broad stenosis ranges (see below). Including quantitative ranges with qualitative descriptions ensures that CCTA reporting is compatible with familiar ICA lumen categories and adds clarity to purely qualitative terms (eg, “moderate”), which often have variable meaning to those receiving these reports. An example of such a description might be: “In the proximal segment of the left anterior descending artery there is a non-calcified plaque causing moderate luminal stenosis in the range of 50%–69%.” There are two quantification ranges in common use. The first listed below is the recommended stenosis grading scale.

Recommended Quantitative Stenosis Grading

0 Normal: Absence of plaque and no luminal stenosis
1 Minimal: Plaque with <25% stenosis
2 Mild: 25%–49% stenosis
3 Moderate: 50%–69% stenosis
4 Severe: 70%–99% stenosis
5 Occluded

Optional Quantitative Stenosis Grading

0 Normal: Absence of plaque and no luminal stenosis
1 Mild: Plaque with <39% stenosis
2 Moderate: 40%–69% stenosis
3 Severe: 70%–99% stenosis
4 Occluded

Total occlusions

Because the method of delivery of contrast (intravenous versus direct interarterial) and the timing of imaging (20–30 seconds after injection) is so different from ICA, it should be understood that chronic or acute total coronary occlusions may show a substantial amount of contrast distal to the occlusion, even when ICA does not reveal collaterals. A limited number of studies suggest that the length of the occluded segment is somewhat predictive of total versus subtotal occlusion. The degree of calcification within the totally occluded segment provides useful information regarding the likely success of percutaneous coronary intervention.

Bypass grafts, stents

There is extensive evidence that evaluation of coronary bypass grafts by CCTA is highly accurate in predicting the
findings on ICA. The location and anastomoses of bypass grafts should be described in addition to the location and severity of stenoses.

The evaluation of lumen patency inside stents is possible in most cases, but the evaluation of in-stent stenosis is highly dependent on stent size and composition. The presence of contrast distal to a stent is not a definitive sign of patency; in such cases it is the reduction of contrast inside the stent lumen in distinction to the vessel beyond the stent that provides the most useful information.

Non-coronary cardiac findings

Non-coronary cardiovascular structures within the field of view of routine CCTA include the pericardium, cardiac chambers, interatrial septum, interventricular septum, atrioventricular valves, ventriculo-arterial valves, pulmonary arteries, pulmonary veins, thoracic aorta, imaged aortic branch arteries, and central systemic veins. These structures should be reviewed within the cardiac field-of-view and any abnormalities described. Left ventricular and left atrial myocardial walls and chamber cavities are uniformly opacified in standard CCTA and should be examined for hypertrophy, dilation, thinning, hypodense enhancement, masses, and congenital anomalies. Depending on the contrast infusion protocol, right-sided chambers and walls may also be suitable for interpretation. Measurement and reporting of chamber and wall dimensions are considered optional but can easily be done with standard workstations. Depending on the nature of acquisition, multiphase reconstruction of these structures may be available to permit dynamic display of ventricular, atrial, and valvular structure and function in 4-dimensional (cine-CT) formats. Reporting of regional and global left ventricular function including quantification may be appropriate, depending on clinical indications.

Extra-cardiac structures

By nature of the imaging technique and coverage, non-contrast calcium scoring and CCTA also display portions of non-cardiovascular thoracic and upper abdominal anatomy, including the mediastinum, hilum, trachea and bronchi, lung parenchyma, pleura, chest wall, esophagus, stomach, liver, spleen, and colon. Review of all visible non-cardiovascular structures is important for two principal reasons: (1) recognition of primary and secondary comorbid pathology and (2) identification of findings that lead to alternative non-cardiovascular diagnoses. The Committee recommends that all structures within the reconstructed cardiac field of view be examined and that, if abnormalities are noted, additional reconstructions and/or expert consultation are requested as clinically warranted.

Part B. Reporting cardiac computed tomographic angiography

Preamble

This document is intended to identify critical factors involved in effective and thorough reporting of cardiac CT angiography studies so that it may serve as a standard for cardiac CT programs.

Introduction

The final task in performing a cardiac CTA procedure is preparation of a written report. As this is often the only document that the referring physician will see, it is of critical importance. The principal purpose of the report is to communicate the findings and their clinical implications.

Structured reporting

Introduction

Structured reporting is increasingly being recommended to assure quality and consistency from site to site and physician to physician. Without structured reporting and consistent terminology, physicians receiving results from different interpreting physicians (even from the same institution) may perceive differences in the results based solely on differences in reporting structure and terminology, rather than actual differences in scan findings. More uniform reporting and terminology would eliminate some of the inherent differences, minimizing one important source of interscan or interreport variability. Key report elements are less likely to be omitted in a structured report where all elements are listed systematically within a standardized template. Standardized reports can convey similar information despite differences in interpreter background or training and improve reporting consistency throughout and across institutions. Referring physicians have access to a document in which pertinent results are in an expected location and described in standard, defined terminology. In addition, data review may be facilitated by linking entries in structured reports to data cells in electronic medical records. While the final output of structure reporting need not be the same from site to site, structured reporting would ensure that all required elements for clear, consistent, and complete description of findings needed for patient care are contained within the report.

Overview of report components

The components of the report include indication(s) for procedure, patient clinical data, technical procedure information (image acquisition data), image quality, clinical scan findings, interpretation, and, when appropriate, clinical recommendation(s) (Table 5).
<table>
<thead>
<tr>
<th>Section</th>
<th>Specific Component(s)</th>
<th>Necessity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>Indication or reason for test, procedure date</td>
<td>Required</td>
</tr>
<tr>
<td>Demographics</td>
<td>Name, date of birth, sex, referring clinician</td>
<td>Required</td>
</tr>
<tr>
<td>Height, weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>History</td>
<td>Symptoms, risk factors, relevant diagnostic tests</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Procedure Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Test type (eg, coronary CT angiography, calcium scoring, ventricular function, pulmonary vein, other)</td>
<td>Required</td>
</tr>
<tr>
<td>Equipment</td>
<td>Scanner type: Number of detectors, rotation time</td>
<td>Required</td>
</tr>
<tr>
<td>Acquisition</td>
<td>Gating method</td>
<td>Recommended</td>
</tr>
<tr>
<td>Tube voltage, dose modulation (if used)</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Estimated radiation dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reconstruction</td>
<td>Slice thickness</td>
<td>Recommended</td>
</tr>
<tr>
<td>Slice increment, reconstruction filter, phases of cardiac cycle</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Medications</td>
<td>Contrast type, volume, β-blockers, nitroglycerin, or any other, if given</td>
<td>Required</td>
</tr>
<tr>
<td>Contrast rate</td>
<td></td>
<td>Recommended</td>
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<tr>
<td>Patient parameters</td>
<td>Complication(s), if present</td>
<td>Required</td>
</tr>
<tr>
<td>Heart rate, arrhythmia, if present</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Results</strong></td>
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<td></td>
</tr>
<tr>
<td>Technical quality</td>
<td>Overall quality</td>
<td>Required</td>
</tr>
<tr>
<td>Calcium score (if calcium scan performed)</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Coronary anomalies (origins and course), if present</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Stenosis location and severity</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Uninterpretable segments, arteries, or overall study</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Stenosis plaque type: Calcified, noncalcified, mixed</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Stenosis extent: Ulceration, length, ostial or branch involvement, positive remodeling, tortuosity</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Use of SCCT stenosis severity classification</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Use of SCCT axial coronary segmentation model</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Calcium score percentile (if calcium scan performed)</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Use of AHA or CASS coronary segment model</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Non-coronary Vessels</td>
<td>Abnormalities of aorta, vena cavae, pulmonary arteries, pulmonary veins, if present</td>
<td>Required</td>
</tr>
<tr>
<td>Pulmonary vein morphology and ostia sizes (required for pre-ablation studies)</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Cardiac chambers</td>
<td>Abnormal chamber dilation, masses, thrombus, shunts, and other structural disease, if present</td>
<td>Required</td>
</tr>
<tr>
<td>Left ventricular size and volume (if function data obtained)</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Left atrial volume (for pre-ablation studies)</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Right ventricular size and volume (if functional data obtained) optional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-coronary</td>
<td>Left ventricular wall motion (17 segment model)</td>
<td>Recommended</td>
</tr>
<tr>
<td>Myocardium</td>
<td>Left ventricular ejection fraction (if functional data obtained) recommended</td>
<td>Required</td>
</tr>
<tr>
<td>End-diastolic left ventricular wall thickness recommended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pericardium</td>
<td>Abnormal thickness, calcification, effusion, if present</td>
<td>Required</td>
</tr>
<tr>
<td>Valves</td>
<td>Abnormal aortic and mitral valve calcification, thickness, if present</td>
<td>Recommended</td>
</tr>
<tr>
<td>Non-cardiac</td>
<td>Abnormalities in lungs, mediastinum, esophagus, bony structures, chest wall, etc, if present</td>
<td>Required</td>
</tr>
<tr>
<td>Impressions and Conclusions</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Coronary interpretation</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Abnormal non-coronary cardiac findings</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Abnormal non-cardiac findings</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Non-coronary cardiac interpretation (ventricular function, etc)</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Correlation to other or prior cardiac studies</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Documentation of communication to referring physician for urgent finding(s)</td>
<td></td>
<td>Recommended</td>
</tr>
<tr>
<td>Clinical recommendations</td>
<td></td>
<td>Optional</td>
</tr>
<tr>
<td>Images</td>
<td>Representative coronary segments</td>
<td>Optional</td>
</tr>
</tbody>
</table>

AHA, American Heart Association; CASS, Myocardial Infarction and Mortality in Coronary Artery Surgery Study; SCCT, Society of Cardiovascular Computed Tomography.
Indications

The specific reason for ordering the test should be identified and documented. This section should include symptoms and applicable ICD-9 code or other information relevant for billing. Major categories of indications for the study include (1) evaluation of coronary arteries for atherosclerosis or anomalies; (2) evaluation of non-coronary pathology, including the great vessels, chambers, myocardium, valves, or pericardium; and (3) evaluation of cardiac chamber function, including ejection fraction and chamber volumes.

Clinical data

Selected clinical information is important to include in the report as it may help the clinician to understand the clinical relevance of various findings identified on the CCTA. Clinical data should include demographics such as patient age, sex, height, weight, procedure date, and referring physician. Clinical history should include pertinent cardiac history, coronary risk factors, medications (optional), prior tests and procedures (such as location and extent of ischemia on prior stress testing), and any clinical risks for contrast administration. See Table 5 for a summary list of clinical data elements.

Procedure

The procedure section of the report can be divided into two major categories: image acquisition and image reconstruction. Table 5 contains a classification of procedure components to be reported, denoted as required, recommended, or optional. Many aspects of image acquisition should be documented in the report, including the type of study or studies; equipment; technical acquisition protocol(s); type, amount, and timing of contrast or other medications; some measure of the radiation dose; and clinical parameters during the procedure, including heart rate and any complications. Current types of studies include calcium scoring, coronary CT angiography, pulmonary vein angiography, cardiac venous angiography, and cardiac morphology and function. Description of the equipment should include at the minimum manufacturer and scanner type (64-slice, 256-slice, 320-slice, or dual source). Description of the technical acquisition protocol should include whether the scan was gated prospectively (axial scanning) or retrospectively (helical scanning). Reporting of the method of scan triggering—bolus tracking or test bolus—is optional. In addition, mAs, kVp, use of any radiation reduction strategies, and a measure of radiation dose (such as dose-length product or CT dose index) should be included. Finally, it is important to include the heart rate and presence of arrhythmia at time of image acquisition. Any adverse effect from contrast or β-blocker administration and subsequent treatment should be described in detail.

A variety of technical elements regarding image reconstruction can be optionally included in the report and are described in Table 5.

Results

Technical quality

It is important to describe the overall study quality and any significant artifacts that might interfere with a thorough interpretation so that the clinician can understand how reliable and accurate the results are. Although there are no standard statements for overall study quality, a scheme such as excellent, good, average, and poor is recommended. If present, inadequacy of overall contrast concentration or contrast opacification should be noted. Noise or signal-to-noise ratio may be measured quantitatively in a region of interest as the standard deviation of Hounsfield units. It is also acceptable to qualitatively report the noise as mild, moderate, or severe, although there is no standardization of these terms.

The artifacts specific to cardiac CT should be included in the report. Artifacts such as misregistration, motion, beam hardening, metal, or calcium-related partial volume averaging should be noted. Whenever a certain section or certain sections of the coronary tree is/are not interpretable because of artifact, that must be clearly stated in the report.

Clinical scan findings

The clinical scan findings or results of the study should be reported in a format which the clinician can easily review. Three broad categories—coronary findings, non-coronary cardiac findings, and non-cardiac findings—are important to include in the report. If acquired, findings from the coronary calcium scan (coronary calcium score) and functional data should be reported.

A complete report of the non-coronary cardiac structures should include abnormalities of the following: (1) great vessels—aorta (including diameter of the ascending and descending thoracic aorta), vena cavae, pulmonary arteries, and veins; (2) cardiac chambers—size and volume (estimation of left atrial size and/or volume can be useful when indication is consideration of ablation for atrial arrhythmia), morphology (aneurysm, diverticulum), masses; (3) myocardium—hypertrophy and infarct; (4) valves—thickening, calcification, masses; and (5) pericardium—thickening, effusion, calcification. More detailed findings may be included in the report as needed.

Results from any reconstructed functional data, such as ejection fraction, chamber size or volumes (if measured), and any other significant abnormalities, should be included. Report of calculated myocardial mass is considered optional.

The coronary arteries should be described in terms of the origin and course and any significant pathology. If coronary disease is present, stenosis severity, plaque morphology,
and extent should be described. Stenosis severity may be described qualitatively (eg, mild, moderate, severe, or occluded) or preferably with an estimated percentage of diameter obstruction, as detailed in Part A.

Plaque type should be described as calcified, non-calcified, or mixed. Other morphologic descriptors of the stenotic lesion, such as extensive length, bifurcation or ostial involvement, location in a tortuous segment, eccentric position, apparent dissection or ulceration, and positive remodeling may also be appropriate. Reporting of Hounsfield units in the plaque is discretion; it must be recognized that significant overlap exists between lipid and fibrous material, making interpretation of plaque Hounsfield unit problematic.

Classification of coronary disease into different segments should be included into the report. The AHA coronary segmentation model is widely used. We have adopted a modification of this model in axial presentation, potentially better suited to clarify variations of distal right and circumflex coronary arterial anatomy, as noted in Part A, section 4.3 above.

If bypass grafts are present, describe the number of grafts and identified graft stumps. Whenever possible, define each graft as arterial or venous (this detail may be obtained from a prior operative or invasive angiographic report). The origin and insertion(s) of each graft must be described. Any significant stenotic pathology should be reported in similar fashion as the native coronaries. Patency of the proximal and distal anastomosis of each graft should be specifically documented. In most circumstances, comparing cardiac CT bypass graft findings with the most recent, available operative or invasive angiography report is recommended.

**Impressions**

The impressions section is critically important and should be prominently displayed in the report. All clinically important scan findings should be summarized in this section in as clear and standardized a fashion as possible. Clinical certainty or uncertainty of the findings should be communicated. For example, a coronary stenosis of unclear clinical significance might be stated as such, and recommendations on further workup for the clinician may be appropriate. When making clinical recommendations, the reporting physician needs to be aware of the study indications and level of cardiac CT familiarity of the referring physician. Such recommendations may vary based on the background of the reader, local custom, and needs of the referring physician and patient. If a particular clinical question was posed, the impression section should answer that question if possible.

“Normal” in reference to the coronary arteries should be used only when there is no evidence of any coronary artery disease (ie, normal lumen and no plaque). Segments containing non-obstructive disease should not be described as normal.

**Images**

Attaching representative images of normal anatomy and important pathology imported from the workstation is recommended. Although such images often do not fully represent the pathology seen at time of interpretation, they serve as important reference points for the referring physician and interventional cardiologist. For referring physicians not familiar with workstation image display, curved multiplanar reconstruction and maximal intensity projection images of coronary arteries may be preferable to multiplanar reformation. Consideration should be given to including representative compressed movies of multiphase studies. Images accompanying the report should be adequately labeled so the referring clinician can understand the anatomy being displayed. A picture included in a report may be worth a thousand words and may help the clinician explain the treatment options to the patient.

**Timeline for report distribution**

Documentation of the date of electronic or physical signature should be included in the report. It is recommended that all potentially life-threatening findings are reported to the referring physician on the same date of the study and that a record of a verbal communication be included in the report. Reports of emergency studies should be issued within 24 hours, and elective studies should be reported within 2 working days of the procedure.

**Conclusions**

In summary, the Committee believes it is critical to generate comprehensive reports for cardiac CT. The report should always contain adequate information to support clinical necessity of the procedure, sufficient technical details to allow reproduction of the study, and sufficient description of the clinical scan findings to allow clear understanding of the implications of the report. We also encourage definitive and clinically relevant descriptions and conclusions.

**Acknowledgments**

The SCCT would like to acknowledge and thank the members of the Guidelines Committee:

Gilbert L. Raff, MD, *Co-Chair*
Wm. Guy Weigold, MD, *Co-Chair*
J. Jeffrey Carr, MD
Mario J. Garcia, MD
Jeffrey C. Hellinger, MD
Michael Poon, MD
References


Appendix

Conflicts of Interest

Dr. Achenbach received research support from Siemens Healthcare and Bayer Schering Pharma.

Dr. Berman has received a research grant from GE Healthcare.

Dr. Boxt has served as consultant to Fuji Medical Systems.

Dr. Budoff served as a consultant to GE Healthcare.

Dr. DeFrance served on the Toshiba Medical Systems and Vital Images Speaker Bureaus.

Dr. Karlsberg served as the director of the GE Training Master Series on Computed Tomography and has received research grants from GE Healthcare.

Dr. Raff received research support from Siemens, Bayer, Blue Cross/Blue Shield of Michigan.

Dr. Weigold served as a consultant to Philips Healthcare, Bracco Diagnostic Imaging, and Parners Imaging. He holds stock options from partners Imaging.

All of the others do not have any conflicts of interest or financial relationships to disclose:

Aiden Abidov, MD, Victor Cheng, MD, Jeffrey Hellinger, MD, Jeffrey Carr, MD, Michael Poon, MD, Mario Garcia, MD
<table>
<thead>
<tr>
<th>Considerations related to indication(s)/patient characteristics</th>
<th>Use Prospective Triggering</th>
<th>Use Retrospective Gating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is radiation dose a concern for this patient?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Young age, especially women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Need to assess LV or RV function or wall motion abnormalities?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Known CAD or high pretest probability of significant CAD?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>High CAC score (i.e., CAC ≥400)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous abnormal stress test result</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation for suspected anomalous coronary arteries (i.e., young patients with low risk of obstructive CAD; main interest is only proximal vessel visualization)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Technical considerations related to likelihood of diagnostic quality scan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is it possible to achieve a low heart rate?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>&lt;60 for single-source scanner; &lt;65 for DSCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there evidence of significant ectopy (frequent PACs or PVCs) on prescan monitoring?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>If calcium scoring is performed, is there evidence of motion artifacts for RCA?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

CAC = coronary artery calcium; CAD = coronary artery disease; LV = left ventricular; RCA = right coronary artery; RV = right ventricular.