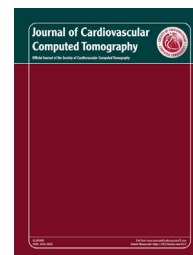




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SCCT Guidelines

SCCT guidelines for the interpretation and reporting of coronary CT angiography: A report of the Society of Cardiovascular Computed Tomography Guidelines Committee



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1. Part A: interpreting coronary CT angiograms

1.1. Preamble

Since the publication of the first guidelines for the interpretation and reporting of coronary CT angiography (coronary CTA) in 2009, there have been significant changes in the scope and utilization of this method. At that time it had only been 5 years since the introduction of 64 detector row scanners. Since then, multiple innovations in scanner design have occurred. Also there has been wide expansion of clinical applications of coronary CTA that are considered “appropriate use” (including, eg, patients with acute chest pain in the emergency department), as well as the development of new techniques allowing for physiologic assessment from coronary CTA. Given these significant changes in technology and scope of practice, the guidelines committee felt it necessary to update the reporting guidelines to ensure that they were aligned with modern clinical practice in coronary CTA. These recommendations, like the preceding version, were developed as an educational tool for practitioners to continue to improve the care for patients, in the interest of developing systematic standards of practice for coronary CTA based on the best available data or broad expert consensus.

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 Committees 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 Writing Group and Committee members are available in the footnotes of this article. These are reviewed by the Guidelines Committee and will be updated as changes occur.

2. Introduction

2.1. Comparison of coronary CTA to invasive coronary angiography

Coronary CTA has important similarities to and differences from invasive coronary angiography (ICA). Decades of research into the prognostic implications of ICA findings^{1–4} provide a solid basis for the classification of the coronary tree and description of stenosis severity in coronary CTA. In these instances, established ICA standards have been used with minimal alteration. However, coronary CTA may also provide information about the presence of extraluminal plaque and plaque composition that is not routinely available on ICA without the use of intravascular imaging.^{5–9} Beyond the coronary arteries, the coronary CTA data set also contains noncoronary cardiac and extracardiac thoracic information of importance,^{10–21} including myocardial, pericardial, and valvular morphology and function as well as aortic and

pulmonary vascular structural detail. Thus, coronary 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 anatomic structures and to the full potential of this technology.

2.2. Limitations of this document

In addition to its use for anatomic evaluation of the coronary arteries, CT 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 coronary CTA. However, an approach to interpreting and reporting of common noncoronary cardiac and extracardiac 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 coronary CTA examination.

2.3. Qualifications of interpreting physicians

Reliable interpretation of coronary angiography by CT 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 CT with and without contrast; (4) the technology and limitations of CT; (5) the use of 3-dimensional cardiac-specific interpretation software; and (6) the ability to identify and overcome image artifacts 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, interpreters of coronary CTA 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.

3. Underlying principles of interpreting Coronary CT Angiography studies

3.1. Three-dimensional data sets and workstations

Coronary CT images should be acquired as isotropic submillimeter 3-dimensional electrocardiography (ECG)-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 coronary CTA interactively on cardiac-specific interpretation software platforms capable of 2- and 3-dimensional displays in all conventional reconstruction formats. These include transaxial 2-dimensional image stacks, multiplanar reformations (MPR), maximum intensity projections (MIP), curved multiplanar reformations (cMPR), 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 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.

3.2. Interpretation formats

3.2.1. Transaxial images

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 depict coronary anatomy 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 postprocessing and the maximum resolution and gray-scale rendering.^{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, as the data are displayed in 2 dimensions and from 1 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 to differentiate contrast-containing lumen from calcified plaque and to preserve the gray-scale subtlety needed to distinguish intramural noncalcified plaque from the interstitium.^{37–39} In general, the window level should be at the mean of the Hounsfield unit (HU) values; 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.

3.2.2. Multiplanar reformation

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 the 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 3 orthogonal oblique MPRs. In addition, it is easy to rotate the region of interest, while the window width should be about 2.5 times the level. As a routine, the interpreting physician should rotate the vessel on its longitudinal axis through 360, 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.^{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.

3.2.3. Maximum Intensity projection

MIP^{41,42} is similar to MPR in that orthogonal or oblique planes can be reviewed interactively. 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). The intensity of each voxel is set at the maximum HU value along its line of intersection in the slab volume between the tube and detectors.³⁷ These features allow the reader to visualize a longer segment of a vessel's course and tend to reduce perceived image noise. However, because of the assignment of maximum intensity value to each voxel, 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.⁴³ Consequently, MIP should never be the sole technique used for interpretation. In general, MIP images are useful for identifying some artifacts, the origin and course of vessels, and the presence and position of lesions but should not be used in isolation to assess stenosis severity or plaque composition because of the aforementioned limitations.

3.2.4. Curved Multiplanar Reformation

The cMPR format was developed to allow the interpreter to follow the course of a tortuous vessel for longer distances as it changes direction.^{40,41} The image is created by tracing the centerline of the artery and producing an MPR along the curving path of the centerline. This requires that the centerline of the vessel be tracked correctly, which can be done manually or automatically. cMPR has the advantage of producing a view of the entire course of the vessel in 1 image and providing a longitudinal and cross-sectional view at any point in its course. It is a highly processed modality and has the potential to produce artifactual lesions unless carefully used by experienced users. It is considered an optional supplement to other formats that should not be used in isolation.

3.2.5. Volume-rendering technique

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 because the apparent thickness of the vessel lumen is dependent on window settings and the computer algorithm that is used to subtract nonvascular structures.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.

Tables 1 and 2 summarize the key underlying principles of interpreting coronary CTA.

4. Noncontrast coronary interpretation: coronary calcium scoring

A preliminary noncontrast examination for coronary artery and other cardiac structural calcification is routine in many centers but not in others where it is constrained to risk assessment in asymptomatic individuals. The use of prospective triggering and other factors reduce 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.^{42–48} 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 HUs as a level corresponding to calcium on a noncontrast study.^{49,50} The reader needs to identify each lesion (discrete calcific focus) in each vessel distribution (right coronary artery, circumflex, left main and left anterior descending). The summed score for each vessel is generated by the scoring program based on either an area-density (Agatston score)⁴⁹ or volumetric⁵¹ measurement of each calcified focus. The mass score^{52–54} is less commonly used in clinical practice. Because there are no current validation data for this measure (no nomograms, outcome studies, histology studies, and so forth), the use of mass score should always be accompanied by reporting of the more traditional (and clinically understood) Agatston score. The same cautions pertain to other proposed methods for calcium scoring.^{55–58} 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.

Table 1 – Underlying principles of coronary CT angiogram interpretation.

- Interpretation should be made on 3-dimensional cardiac-specific interpretation software equipped to display recommended image reconstruction formats
- Images should be reviewed in the appropriate post-processing formats (Table 2)
- Interpreters should be prepared to customize image reconstructions if necessary
- The data set should be previewed for artifacts
- Noncontrast studies should be reviewed before contrast studies
- The coronary tree should be examined systematically
- Lesions should be reviewed in multiple planes and conceptualized in 3 dimensions
- Lesions should be assessed for extent, quality, and morphology of plaque, not just for stenosis severity
- Extracoronary cardiac and thoracic anatomy should be examined within the cardiac field of view

Table 2 – Recommended image post-processing formats.

Format	
• Axial image review	Recommended
• Multiplanar reformation image review	Recommended
• Maximum intensity projection image review	Recommended
• Curved multiplanar reformation image review	Optional
• Volume-rendered reconstructions	Consider under limited circumstances

Reporting of the calcium score is somewhat dependent on reader preference, but at the minimum, the total calcium score should be reported as well as the percentile as compared with age and gender nomograms.⁵⁹ 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, or severe calcification) as a preferred but optional reporting method, as these measures may have independent prognostic and diagnostic value.

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

5. Coronary artery angiography interpretation

5.1. Examination of image quality

Because of the constant motion of the heart and the intrinsic limitations of CT, 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.^{60–62} This is sufficiently common to require identification of artifacts before definitive image interpretation.

Table 3 – Required and optional reporting on coronary calcium noncontrast CT.

Report
Required
Agatston score for total study (sum of 4 vessels)
Agatston score percentile based on age and sex normogram (representative cohort for population being evaluated should be considered)
Presence of calcium in aortic wall, aortic valve, mitral annulus/valve, pericardium, and myocardium
Noncardiac structures (pleural effusions, pulmonary nodules, mediastinal abnormalities, and so forth)
Optional
Agatston score for each vessel
Further delineation of calcium score by branches (posterior descending, diagonals)
Number of lesions: per vessel and total
Volumetric or mass score: per vessel and total
Aortic valve calcium score
Dilated chambers or total heart enlargement
Pericardial effusions/thickening/pericardial fat

5.1.1. Reconstruction artifacts

“Stairstep artifacts” have been recently renamed as misalignment artifacts⁶³ and are because of the motion occurring between the 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 midvessel 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.

5.1.2. Metal density artifacts

Metal density artifacts include beam hardening, blooming, and streaking. Dark beam-hardening artifacts may simulate 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.

5.1.3. Reduced signal-to-noise and low vessel contrast intensity

Image quality may be impaired by poor signal to noise, which can be because of 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 electrocardiography-guided tube modulation. Low contrast intensity may be secondary to improper image acquisition timing or slow contrast injection.

5.2. 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 coronal and sagittal planes may aid in the identification of artifacts. Many experienced readers will review the arterial tree in detail, beginning in the axial (caudal) view as the transaxial data are more robust, as they are the least processed (Table 4).

5.3. Coronary segmentation

A standardized approach to coronary segmentation improves description and communication of findings. The standard American Heart Association (AHA) segmentation¹ 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 coronary CTA 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 that was used in the Myocardial Infarction and Mortality in Coronary Artery Surgery Study⁶⁴ (Table 5).

5.4. 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 sub-branches. 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 to determine the overall myocardium risk. The impact of luminal plaque should be evaluated in terms of resultant maximal percent diameter stenosis. Other measures such as minimal luminal area and percent area stenosis are additive but are not required. Because coronary CTA can visualize intramural presence of positively remodeled plaque and differentiate calcific, noncalcific, and partially noncalcified⁶³ plaque, these attributes should also be examined and reported in a segmental fashion. Description of plaques as “noncalcific” is preferable to “soft” or “lipid rich” as low CT density (HU) 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”. Other entities such as coronary aneurysms should stimulate investigation of other associated vascular pathology in the noncardiac thoracic portion of the examination.

5.5. Qualitative assessment of stenosis severity

The ultimate objective of the 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 coronary CTA reader of the strengths and limitations of coronary CTA as well as how it differs from invasive angiography's luminal information and from functional tests that directly test

Table 4 – Components of comprehensive-gated contrast-enhanced cardiac CT reporting.

Section	Specific component(s)	Necessity
Clinical data		
General	Indication or reason for test, procedure date	Required
Demographics	Name, date of birth, sex, referring clinician	Required
	Height, weight, BMI	Recommended
History	Symptoms, risk factors, relevant diagnostic test results	Recommended
Procedure data		
Description	Test type (eg, coronary CT angiography, calcium scoring, ventricular function, pulmonary vein, other)	Required
Equipment	Scanner type: number of detectors, number of x-ray sources, z-axis coverage	Recommended
Acquisition	Scan mode, ECG-synchronization, use of dual energy	Recommended
	Tube potential, tube current, dose modulation (if used)	Recommended
	Dose-length product	Recommended
Reconstruction	Scanned or reconstructed phase of the cardiac cycle	Recommended
	Slice thickness, slice increment, reconstruction filter	Optional
Medications	Beta-blockers, nitroglycerin, type and volume of contrast or any other, if given	Required
	Contrast injection rate	Optional
Patient parameters	Complication(s), if present	Required
	Heart rate, heart rhythm other than sinus rhythm, arrhythmia, if present	Recommended
Results		
Technical quality	Overall quality	Required
	Presence and type of artifact and effect on interpretation	Recommended
Coronary	Calcium score (if calcium scan performed)	Required
	Coronary anatomy: coronary dominance, anomalies (origins and course), dilation/aneurysms, (benign) anatomical variance, myocardial bridging	Required
	Stenosis location and severity	Required
	Uninterpretable segments, arteries, or overall study.	Required
	Stenosis plaque type: Calcified, predominant calcified, noncalcified, predominant non-calcified, outward remodeling	Recommended
	Stenosis extent: length, ostial, or branch involvement, positive remodeling, tortuosity	Recommended
	Use of SCCT stenosis severity classification	Recommended
	Use of SCCT axial coronary segmentation model	Recommended
	Calcium score percentile based on database representative of the cohort being assessed (if calcium scan performed)	Optional
	Use of AHA or CASS coronary segment model	Optional
Prior cardiac procedures	Prior PCI: location of stents, interpretability, patency	Required
	Prior CABG: type, location, course and anastomoses of bypass grafts, interpretability, patency, stenosis	Required
Noncoronary Vessels	Abnormalities of aorta, vena cavae, pulmonary arteries, pulmonary veins, if present	Required
Cardiac chambers	Abnormal chamber dilation, masses, thrombus, shunts, and other structural disease, if present	Required
	Ventricular and atrial sizes and volumes. (if function data obtained)	Optional
	Left ventricular ejection fraction (if functional data obtained)	Recommended
Myocardium		
	End-diastolic left ventricular wall thickness	Recommended
	Evidence of myocardial infarction—hypoperfusion, LV thinning (aneurysm), intramyocardial fat or calcifications	Recommended
Pericardium	Abnormal thickness, calcification, effusion, if present	Required
Valves	Abnormal aortic and mitral valve calcification, thickness, stenosis, incomplete closure, if present and required cardiac phases available	Recommended
	Prosthetic valves: type and location of replaced valves, pannus, thrombus, evidence of restricted mobility	Recommended
Other	Devices: type and location of ICD/PM wires, abnormalities	Required
Noncardiac	Abnormalities in lungs, mediastinum, esophagus, bony structures, chest wall, etc, if present	Required
Impressions and conclusions		
Images	Coronary interpretation	Required
	Abnormal noncoronary cardiac findings	Required
	Abnormal noncardiac findings	Required
	Correlation to other or prior cardiac studies	Recommended
	Documentation of communication to referring physician for urgent finding(s)	Recommended
	Clinical recommendations	Optional
	Representative images of identified pathology	Optional

AHA, American Heart Association; BMI, body mass index; CABG, coronary artery bypass grafting; CASS, Coronary Artery Surgery Study; ECG, electrocardiography; LV, left ventricle; SCCT, Society of Cardiovascular Computed Tomography.

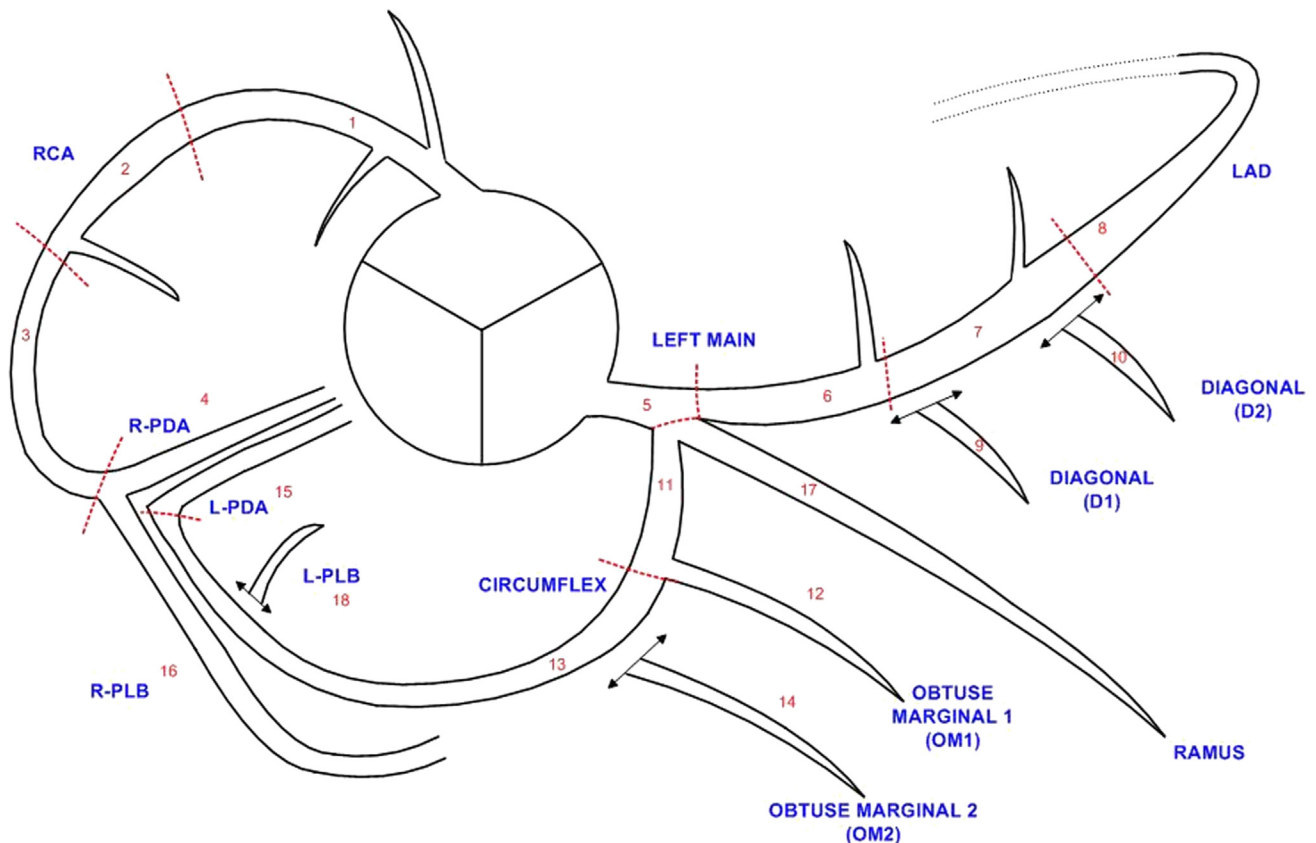


Fig. 1 – Society of Cardiovascular Computed Tomography (SCCT) coronary segmentation diagram. Dashed lines represent division between RCA, LAD, and LCx and the end of the LM. PLB, posterior-lateral branch; PLV, posterior left ventricular branch. Definitions derived and adjusted from the report by Austen et al.¹ The abbreviation and description for each segment can be found in [Appendix 1](#). 2009. Society of Cardiovascular Computed Tomography.

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 mentioned in the following text. Also, interpretation may convey the reader's expert opinion on the potential pathophysiologic importance of a lesion. In addition, the reader should specifically state if an artery or artery segment is not interpretable and why. The following qualitative descriptors and their corresponding meaning are recommended:

- 0—Normal: absence of plaque and no luminal stenosis
- 1—Minimal: plaque with negligible impact on lumen
- 2—Mild: plaque with mild narrowing of the lumen.
- 3—Moderate: plaque with moderate stenosis that may be of hemodynamic significance
- 4—Severe: plaque with probable flow limiting disease.
- 5—Occluded

5.6. 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^{65–68} have reported that coronary CTA quantification of lesion severity in terms of percent maximal diameter stenosis has good general correlation with quantitative invasive angiography and intravascular ultrasound, but with a relatively large standard deviation. These comparative studies suggest that, at a 95% confidence limit, coronary CTA currently predicts quantitative invasive angiography to within $\pm 25\%$ at the 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.^{67,69} Including quantitative ranges with qualitative descriptions ensures that coronary CTA 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% to 69%.” There are 2 quantification ranges in common use.^{69,70} The first listed in the following text is the recommended stenosis grading scale.

Table 5 – Alternative coronary artery segmentation model (CASS Principle Investigators and their associates. Myocardial infarction and mortality in Coronary Artery Surgery Study [CASS] randomized trial. *N Engl J Med.* 1984;310:750–758⁵³).

Segment	CASS number
RCA, proximal	1
RCA, mid	2
RCA, distal	3
PDA	4
RPAS	5
RPL1	6
RPL2	7
RPL3	8
RPL4	9
RV	10
Left main	11
LAD, proximal	12
LAD, mid	13
LAD, distal	14
Diagonal 1	15
Diagonal 2	16
Septal	17
Left circumflex, proximal	18
Left circumflex, distal	19
Obtuse marginal 1	20
Obtuse marginal 2	21
Obtuse marginal 3	22
LPL1	23
LPL2	24
LPL3	25
Left PDA	27
Ramus (optional)	28

LAD, left anterior descending artery; LPL, left posterolateral; PDA, posterior descending artery; RCA, right coronary artery; RPAS, right posterior atrioventricular segment; RPL, right posterolateral; RV, right ventricle.

Recommended stenosis grading

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

5.7. Total occlusions

Because the method of delivery of contrast (intravenous vs 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^{71–73} suggest that the length of the segment without intraluminal contrast enhancement in CT is somewhat predictive of total vs subtotal occlusion. The degree of calcification within the totally occluded segment provides useful information regarding the likelihood of success if percutaneous coronary intervention (PCI) of a chronic total occlusion is attempted.

5.8. Bypass grafts and stents

There is extensive evidence that evaluation of coronary bypass grafts by coronary CTA is highly accurate in predicting the findings on ICA.^{74–78} 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,^{79–84} 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. Recent technological advancements that have improved spatial resolution have allowed for improved evaluation of coronary stents.⁸⁵ In addition, with the recent introduction of bioabsorbable stents and radiolucent scaffolds^{86,87} the ability to assess patients after PCI with multidetector CT is a moving target.

6. Noncoronary cardiac findings

Noncoronary cardiovascular structures within the field of view of routine CCTA include the pericardium, cardiac chambers, interatrial septum, interventricular septum, atrioventricular valves, ventriculoarterial valves, pulmonary arteries, pulmonary veins, thoracic aorta, imaged aortic branch arteries, and central systemic veins. 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. Shunting between the atria, or ventricles, may be visible depending on the contrast injection protocol and should be mentioned. Measurement and reporting of chamber and wall dimensions is considered optional but can easily be done with standard workstations.^{88–95} It should be recognized that most contemporary scan protocols do not include the true end-diastolic phase, and mid-diastolic or end-systolic measures of ventricular cavity size and wall thickness may not be representative.^{96–98} 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. A morphologic assessment of the valves may be appropriate, including calcification, thickening, or other structural abnormalities. Depending on the displayed cardiac phase, morphologic evidence, valvular stenosis, or even regurgitation may be present.^{99–101} Reporting of regional and global left ventricular function and valvular pathology may be appropriate depending on clinical indications and availability of prior knowledge from previously performed (imaging) tests dedicated to this task.^{102,103}

6.1. Myocardial enhancement by cardiac CT

Myocardial CT enhancement patterns can and should be assessed during performance of routine coronary CT

angiography. During the arterial phase of a CCTA study, hypodense areas within the myocardium can represent decreased myocardial perfusion as a result of (prior) myocardial infarction or severe obstructive coronary artery disease, but can also be the result of beam-hardening artifacts. There is now extensive literature validating the use of rest myocardial CT perfusion for detection of myocardial infarct. Old myocardial infarcts are characterized by ventricular wall thinning, hypoenhancement, left ventricular remodeling and/or presence of calcifications, and wall thrombus. There are important considerations for correct interpretation of the left ventricular myocardium as follows^{104–108}:

1. Reconstructions in the cardiac planes (short-axis, 4-chamber, and 2-chamber views) with primary interpretation using the short-axis view.
2. Use of 5- to 8-mm thick averaged MPR reconstructions to improve the detection of hypoenhanced areas in the myocardium. Alternatively, minimum intensity projection reconstructions can be useful. Maximum intensity projection reconstructions must be avoided for assessment of myocardial enhancement because of the potential masking of perfusion defects.
3. A narrow window width and window level is recommended (eg, window width 200 and window length 100) to improve the detection of perfusion defects.
4. Typical locations for artifacts due to beam-hardening are the basal inferolateral wall and the left ventricular apex.
5. Multiple phases of the cardiac cycle should be used if available to differentiate a true perfusion defect from artifacts. The true perfusion defect will persist in several phases of the cardiac cycle while artifacts may vary in presence and location.
6. Comprehensive evaluation of myocardial enhancement, function, and coronary anatomy should be performed if a multiphase data set is available (eg, retrospectively gated acquisition). This will allow the detection of a perfusion defect in the same location of an area of regional wall motion abnormality and will help in the differentiation of beam-hardening artifacts. In addition, a true regional perfusion defect will be unlikely in the absence of obstructive coronary artery disease or prior revascularization procedure (stent or bypass graft).
7. A second CT scan may be performed 5 to 10 minutes after coronary CTA to demonstrate hyperenhancement in a region of prior myocardial infarction, preferably using dose reduction techniques.

The coronary CTA scan can be complemented by a myocardial perfusion scan to assess the hemodynamic significance of angiographic coronary artery disease. Myocardial CT perfusion imaging is performed by imaging the heart during pharmacologic vasodilation, that is, the administration of adenosine, regadenoson, and dipyridamole. Hypoenhancement of myocardium during vasodilation indicates myocardial ischemia. There are growing data from both several single-center studies and, most recently, multicenter trials which indicate that stress CT perfusion is noninferior to single photon emission CT myocardial perfusion imaging to detect myocardial ischemia and infarct.^{109–111} In case of a single scan

during vasodilation, the same principles described previously apply for the interpretation of stress myocardial CT. Alternatively, myocardial enhancement can be imaged in a dynamic fashion, in which case enhancement of the myocardium is imaged during a sequence of scans. Dynamic CT perfusion protocols allow for calculation of absolute blood flow in the myocardium, and have shown good correlation in comparison to invasive fractional flow reserve.^{112,113}

7. Extracardiac structures

By nature of the imaging technique and coverage, noncontrast calcium scoring and coronary CTA also display portions of noncardiovascular thoracic and upper abdominal anatomy, including the mediastinum, hilum, airway, lung parenchyma, pleura, chest wall, esophagus, stomach, liver, spleen, and colon. Review of all visible noncardiovascular structures is important for 2 principal reasons: (1) recognition of primary and secondary comorbid pathology, and (2) identification of findings that lead to alternative noncardiovascular diagnoses. Until recently, there were limited data supporting the benefit of incidental nodule detection and chest CT with management decisions guided by consensus opinion.¹¹² The National Lung Screening Trial has provided clear evidence of lung cancer mortality reduction with CT screening of high-risk patients (age 55–75 years with >35 pack-years smoking history).¹¹³ 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. In addition, given the new data supporting screening of those at high risk for lung cancer with MDCT that patients that would otherwise meet, the National Lung Cancer Screening Trial inclusion criteria have the entire field of view reviewed for potential pulmonary abnormalities.

8. Part B: reporting cardiac CTA

8.1. Preamble

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

9. Introduction

The final task in performing a coronary 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.

10. Structured reporting

10.1. Introduction

Structured reporting is increasingly 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 eliminates some of the inherent differences, minimizing an important source of interscan or inter-report 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. Although 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.

10.2. 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).

10.3. Indications

The specific reason for ordering the test should be identified and documented. This section should include symptoms and applicable ICD-9 code (beginning in October first 2015, ICD-10 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 noncoronary pathology including the great vessels, chambers, myocardium, valves, or pericardium; (3) evaluation of cardiac chamber function, including ejection fraction and chamber volumes; (4) evaluation of low-to-intermediate risk symptomatic patients presenting with symptoms of stable angina or acute chest pain; and (5) discordant or inconclusive stress tests.

10.4. 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 coronary CTA. Clinical data should include demographics such as patient age, gender, body mass index, procedure date, and referring physician. Clinical history should include pertinent cardiac history, nature and status of symptoms, 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. [Table 4](#) provides a summary list of clinical data elements.

10.5. Procedure

The procedure section of the report can be divided into 2 major categories: “image acquisition” and “image reconstruction.” 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 CTA, but contrast-enhanced cardiac CT may also be performed to image the pulmonary veins, the cardiac veins, the left ventricular outflow tract, congenital heart disease, or other cardiac morphology. Description of the equipment should include, at minimum, the scanner type (64-slice, 128-slice, 256-slice, 320-slice, or dual-source CT). Description of the technical acquisition protocol should include the mode of data acquisition and ECG synchronization: retrospectively ECG-gated spiral or helical acquisition, prospectively ECG-triggered axial acquisition, or prospectively ECG-triggered high-pitch spiral or helical acquisition. Reporting of the method of scan triggering relative to contrast injection—bolus tracking or test bolus—is optional. In addition, the tube current, tube potential, use of any radiation-reduction strategies, and the dose-length product should be included. Finally, it is important to include the heart rate and presence of arrhythmia at the time of image acquisition. Any adverse effect from contrast or beta 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 4](#).

10.6. Results

10.6.1. Technical quality

It is important to describe the overall study quality and any significant artifacts that may have affected 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 with expected tissue homogeneity as the standard deviation of HUs. 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 longitudinal misalignment or phase inconsistency (patient movement, ECG misregistration, arrhythmia), motion blurring, beam hardening, metal, or calcium-related partial volume artifacts should be noted. Whenever a certain section or sections of the coronary tree is or are not interpretable because of artifact, it must be clearly stated in the report.

10.6.2. 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, noncoronary cardiac findings, and noncardiac 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 when available.

A complete report of the noncoronary 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, morphology (aneurysm, diverticulum), and masses; (3) myocardium—hypertrophy, thinning or aneurysm, and infarction; (4) valves—thickening, calcification, and masses; (5) pericardium—thickening, effusion, and 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 the calculated myocardial mass is considered optional.

Coronary anatomy should be described in terms of left or right dominance and includes potentially relevant variance (absent left main, myocardial bridging). Coronary anomalies should be described in terms of the origin, course, lumen caliber, and termination. 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, predominant calcified, noncalcified, predominant noncalcified, or partially noncalcified. Calcium score quantification should be included when available as per the recommendations mentioned previously. Other morphologic descriptors of a 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. In case of planned recanalization, a detailed description of completely occluded vessels will include stump morphology, the presence of side branches, the presence of calcium especially at the entry site, overall degree of calcification, tortuosity, and estimated occlusion length. Reporting of HUs in the plaque is discretionary; it must be recognized that significant overlap exists between lipid and fibrous material, making interpretation of plaque HU problematic.

Classification of coronary disease into different segments should be included into the report. The AHA coronary segmentation model¹ is widely used. The Society of

Cardiovascular Computed Tomography has 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 section 4.3 of part A.

If bypass grafts are present, the number of grafts and identified graft stumps must be described. Whenever possible, each graft should be defined 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 as well as the distal runoff vessels should be specifically documented. In case of planned (redo) cardiac surgery, a detailed description of the location of patent grafts relative to the chest wall is required. In most circumstances, comparing cardiac CT bypass graft findings to the most recent available operative or invasive angiography report is recommended.

If coronary stents are present, their location, interpretability, and the presence of obstruction should be described explicitly. When interpretable, stents should generally be described as having mild in-stent re-stenosis (<50%), significant in-stent disease (50%–99%), or stent occlusion.

10.7. Impressions

The impressions section is critically important and should be prominently displayed in the report. All clinically important findings should be summarized in this section in as clear and standardized 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 the 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 nonobstructive atherosclerotic plaque should not be described as normal.

10.8. 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 when seen at the time of interpretation, they serve as important reference points for the referring physician and the 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 MPR. 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 help the clinician explain the treatment options to the patient.

11. 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.

11.1. Archiving

The amount of data that can be reconstructed from a cardiac CT scan is substantial, and most institutions will restrict the amount of data stored for later retrieval. The minimum data that need to be stored are:

1. Patient protocol; ECG recording (recommended).
2. Calcium scan and quantification results (required).
3. Cardiac reconstruction least affected by artifacts (best phase) and optimized with respect to the clinical indication (kernel). If the scan is not “perfect,” alternative reconstructions of other phases and different kernels should be included (required).
4. Processed and labeled images displaying identified pathology (recommended).
5. Wide-field reconstructions including the entire chest. These reconstructions can have a wide slice thickness (required).

12. 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 and sufficient description of the findings to allow clear understanding of the clinical implications of the report. The committee also encourages definitive and clinically relevant descriptions and conclusions.

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Appendix

Appendix 1 – Axial coronary anatomy legend¹

Segment	Abbreviation	Description
1. Proximal right coronary artery (RCA)	pRCA	Ostium of the RCA to one-half the distance to the acute margin of heart
2. Mid RCA	mRCA	End of proximal RCA to the acute margin of heart
3. Distal RCA	dRCA	End of mid RCA to origin of the PDA (posterior descending artery)
4. PDA-R	R-PDA	PDA from RCA
5. Left main (LM)	LM	Ostium of LM to bifurcation of LAD (left anterior descending artery) and LCx (left circumflex artery)
6. Proximal LAD	pLAD	End of LM to the first large septal or D1 (first diagonal; >1.5 mm in size) whichever is most proximal
7. Mid LAD	mLAD	End of proximal LAD to one-half the distance to the apex
8. Distal LAD	dLAD	End of mid LAD to end of LAD
9. D1	D1	First diagonal branch D1
10. D2	D2	Second diagonal branch D2
11. Proximal LCx	pCx	End of LM to the origin of the OM1 (first obtuse marginal)
12. OM1	OM1	First OM1 traversing the lateral wall of the left ventricle
13. Mid and distal LCx	LCx	Traveling in the atrioventricular groove, distal to the OM1 branch to the end of the vessel or origin of the L-PDA (left PDA)
14. OM2	OM2	Second marginal OM2
15. PDA-L	L-PDA	PDA from LCx
16. PLB-R	R-PLB	PLB from RCA
17. Ramus intermedius	RI	Vessel originating from the left main between the LAD and LCx in case of a trifurcation
18. PLB-L	L-PLB	PLB from LCx
PLB, posterior-lateral branch.		
Additional nomenclature may be added, for example, D3, R-PDA2, saphenous vein graft, and mLAD.		
¹ Definitions derived, adopted, and adjusted from the report by Austen et al. ¹		