SCCT Guidelines for the Interpretation and Reporting of Coronary Computed Tomographic Angiography

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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.

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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.

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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 societies[26] 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 reformations (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.[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.[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.[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.

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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.[40,41] 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.[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.[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.[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.[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 1 Underlying principles of CCTA interpretation

Interpretation should be made on 3-dimensional workstations equipped to display recommended image reconstruction formats.
Images should be reviewed in the appropriate post-processing formats. (See Table 2)
Interpreters should be prepared to customize image reconstructions if necessary.
The data set should be previewed for artifacts.
Non-contrast studies should be reviewed prior to 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 and quality of plaque, not just for stenosis severity.
Extra-coronary cardiac and thoracic anatomy should be examined within the cardiac field of view.

Table 2 Recommended image post-processing formats

Post-processing formats	Recommendation
Axial image review	Recommended
Multiplanar reformation (MPR) image review	Recommended
Maximum intensity projection (MIP) image review	Recommended
Curved multiplanar reformation (cMPR) image review	Optional
Volume-rendered reconstructions	Not recommended

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

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volumetric[46] 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 3 Required and optional reporting on coromary calcium non-contrast CT

Required
Agaston score for each vessel
Agaston score for total study (sum of 4 vessels)
Presence of calcium in aortic wall, aortic valve, mitral annulus/valve, pericardium, and myocardium
Optional
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
Aortic wall calcium score
Mitral annular calcium score
Dilated chambers or total heart enlargement
Pericardial effusions/thickening/pericardial fat
Non-cardiac structures (pleural effusions, pulmonary nodules, mediastinal abnormalities, etc)

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[50–52] stenoses. 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-resolu-

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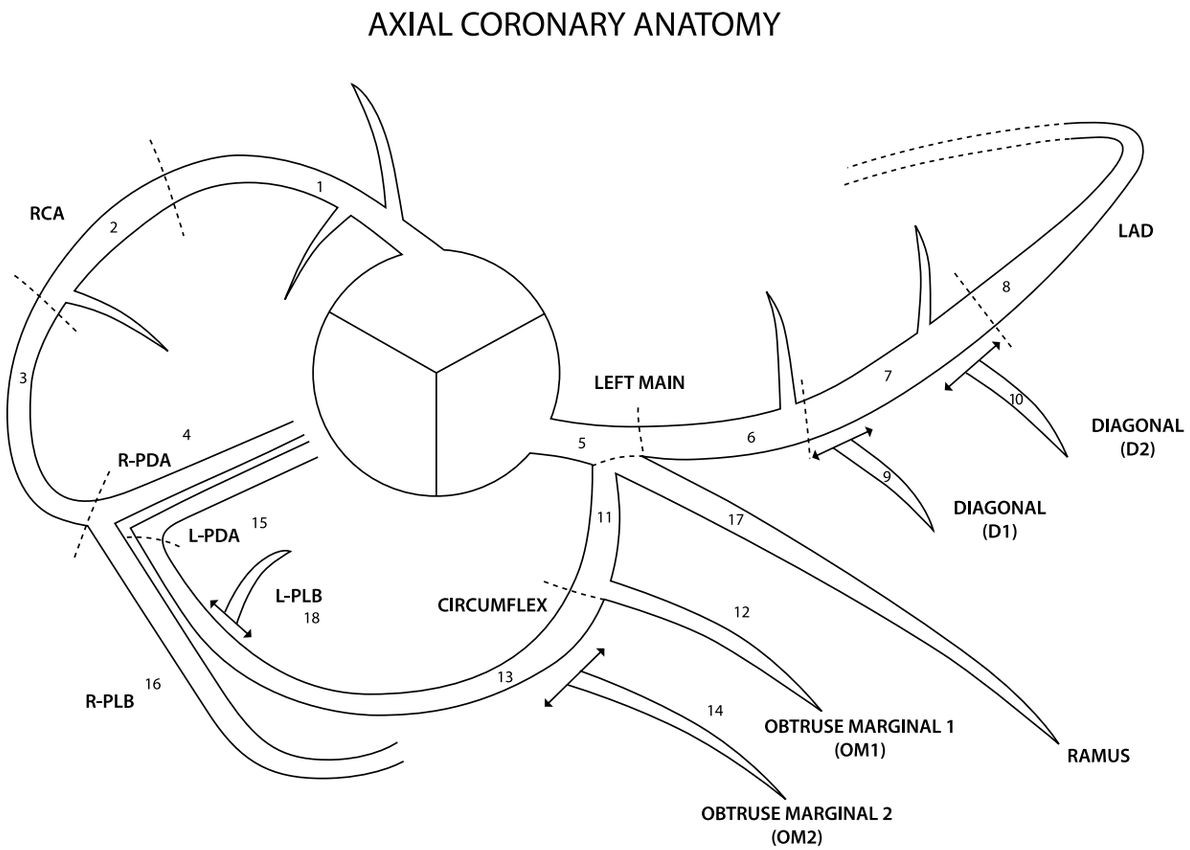


Figure 1 SCCT Coronary Segmentation Diagram. Axial coronary anatomy definitions derived, adopted, and adjusted from WG Austen, JE Edwards, RL Frye, GG Gensini, VL Gott, LS Griffith, DC McGoon, ML Murphy, BB Roe: A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation. 1975;51:5–40.

tion 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.[1] 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)[53] (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

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Segment	Abbreviation	Description
Proximal RCA	pRCA	Ostium of the RCA (right coronary artery) to one-half the distance to the acute margin of heart
Mid RCA	mRCA	End of proximal RCA to the acute margin of heart
Distal RCA	dRCA	End of mid RCA to origin of the PDA (posterior descending artery)
PDA-RCA	R-PDA	PDA from RCA
PLB-RCA	R-PLB	PLB (posterior-lateral branch) from RCA
LM	LM	Ostium of LM (left main) to bifurcation of LAD (left anterior descending artery) and LCx (left circumflex artery)
Proximal LAD	pLAD	End of LM to the first large septal or D1(first diagonal), whichever is most proximal
Mid LAD	mLAD	End of proximal LAD to one-half the distance to the apex
Distal LAD	dLAD	End of mid LAD to end of LAD
Diagonal 1	D1	First diagonal branch D1
Diagonal 2	D2	Second diagonal branch D2
Proximal LCx	pCx	End of LM to the origin of the OM1 (first obtuse marginal)
OM1	OM1	First OM1 traversing the lateral wall of the left ventricle
Mid and distal LCx	LCx	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)
OM2	OM2	Second marginal OM2
PDA-LCx	L-PDA	PDA from LCx
Ramus intermedius	RI	Vessel originating from the left main between the LAD and LCx in case of a trifurcation
PLB-L	L-PLB	PLB from LCx Dashed lines represent division between RCA, LAD, and LCx and the end of the LMPLB 5 PLV (posterior left ventricular branch) Additional nomenclature may be added for example: D3, R-PDA2, SVG (saphenous vein graft) mLAD

in terms of the resultant maximal percentage of diameter stenosis and, optionally, percentage of area stenosis. Since CCTA can visualize intramural presence of positively remodeled 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 following qualitative descriptors and their corresponding meaning are recommended:

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

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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.[54–57] 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[56,58] (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 (e.g. "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 noncalcified plaque causing moderate luminal stenosis in the range of 50%–69%." There are two quantification ranges in common use.[58,59] 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

Table 4 Alternative coronary artery segmentation model

Segment	CASS Number
RCA, proximal	1
RCA, mid	2
RCA, distal	3
PDA	4
PLSA	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
Obtruse marginal 1	20
Obtruse marginal 2	21
Obtruse marginal 3	22
LPL1	23
LPL2	24
LPL3	25
Left PDA	27
Ramus (optional)	28

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

Source: Myocardial infarction and mortality in coronary artery surgery study (CASS) randomized trial. N Engl J Med. 1984;310: 750–758.[53]

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.[60–62] 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 ICA.[63–67] findings on 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,[68–73] 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.

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Table 5	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	Recommended
History	Symptoms, risk factors, relevant diagnostic tests	Recommended
Procedure Data		
Description	Test type (eg, coronary CT angiography, calcium scoring, ventricular function, pulmonary vein, other)	Required
Equipment	Scanner type: Number of detectors, rotation time	Recommended
Acquisition	Gating method	Required
	Tube voltage, dose modulation (if used)	Recommended
	Estimated radiation dose	Optional
Reconstruction	Slice thickness	Recommended
	Slice increment, reconstruction filter, phases of cardiac cycle	Optional
Medications	Contrast type, volume, b-blockers, nitroglycerin, or any other, if given	Required
	Contrast rate	Recommended
Patient parameters	Complication(s), if present	Required
	Heart rate, 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 anomalies (origins and course), if present	Required
	Stenosis location and severity	Required
	Uninterpretable segments, arteries, or overall study	Required
	Stenosis plaque type: Calcified, noncalcified, mixed	Recommended
	Stenosis extent: Ulceration, 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 (if calcium scan performed)	Optional
	Use of AHA or CASS coronary segment model	Optional
	Abnormalities of aorta, vena cavae, pulmonary arteries, pulmonary veins, if present	Required
	Pulmonary vein morphology and ostia sizes (required for pre-ablation studies)	Optional
Cardiac chambers	Abnormal chamber dilation, masses, thrombus, shunts, and other structural disease, if present	Required
	Left ventricular size and volume (if function data obtained)	Recommended
	Left atrial volume (for pre-ablation studies)	Optional
	Right ventricular size and volume (if functional data obtained)	Optional
Non-coronary	Left ventricular wall motion (17 segment model)	Recommended
Myocardium	Left ventricular ejection fraction (if functional data obtained)	Recommended
	End-diastolic left ventricular wall thickness	Recommended

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Pericardium	Abnormal thickness, calcification, effusion, if present	Required
Valves	Abnormal aortic and mitral valve calcification, thickness, if present	Recommended
Non-cardiac	Abnormalities in lungs, mediastinum, esophagus, bony structures, chest wall, etc, if present	Required
Impressions and Conclusions	Coronary interpretation	Required
	Abnormal non-coronary cardiac findings	Required
	Abnormal non-cardiac findings	Required
	Non-coronary cardiac interpretation (ventricular function, etc)	Recommended
	Correlation to other or prior cardiac studies	Recommended
	Documentation of communication to referring physician for urgent finding(s)	Recommended
	Clinical recommendations	Optional
Images	Representative coronary segments	Optional

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

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.[74–80] 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 re-

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ports 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.[81–83]

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).

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 ß-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)

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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 (e.g. 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 discretional; 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.[1] 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 (i.e. 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.

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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:
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