Anatomy and Terminology for the Interpretation and Reporting of Cardiac MDCT: Part I, Structured Report, Coronary Calcium Screening, and Coronary Artery Anatomy

OBJECTIVE. In this part one of a two-part article, we aim to illustrate our understanding of and approach to comprehensive cardiac CT reporting, cardiac CT technique, and coronary calcium scoring CT, as well as normal and anomalous coronary artery anatomy.

CONCLUSION. Structured cardiac CT reporting is important to effectively communicate with referring clinicians. Knowledge of cardiac CT technique, cardiac anatomy, and standard anatomic and physiologic terminology can assist the reader in creating a consistent and comprehensive cardiac CT report.

Cardiovascular disease has been the leading cause of mortality in the United States since 1958 [1]. Coronary artery disease (CAD) leads the group of cardiovascular diseases in contributing to mortality. Many noninvasive tests are used to evaluate patients with suspected CAD, including the exercise treadmill test, echocardiography, myocardial perfusion scintigraphy, and electron-beam CT (EBCT). Invasive catheter coronary angiography with or without intravascular sonography is reserved for patients with a sufficiently high probability of disease to warrant this more invasive and more expensive test with its associated risk of morbidity and mortality [2–4]. Recent advances in CT technology allow noninvasive coronary CT angiography (CTA) and left ventricular (LV) functional assessment. Since its introduction, coronary CTA has become increasingly accepted as a quick and safe noninvasive coronary artery evaluation tool. Coronary artery stenosis detection, accuracy, and negative predictive value using coronary CTA are more impressively performed with 64-MDCT scanners than with 16- or 4-MDCT scanners [5, 6]. Further improvements are being explored in areas such as better CT resolution (both spatial and temporal), dual-source CT [7–16], CT radiation dose reduction, and the feasibility of coronary CTA in patients with suboptimal heart rates [17–19]. The usefulness of coronary CTA as a comprehensive diagnostic tool has also been recently explored in the emergent management of patients with acute chest pain [20–27]. Early experience on feasibility and usefulness of coronary CTA using 320 detector rows has been reported [28, 29]. Recently, the prognostic value of coronary CTA has also been reported in a large group of patients [30].

To perform the coronary CTA examination, interpret, and create a structured coronary CTA report of findings, it is important to have a good understanding of the coronary CTA procedure, anatomy, pathology, and the standard descriptions used in the reference cardiac tests such as invasive catheter coronary angiography and echocardiography. In the current climate of increasing utilization of cross-sectional imaging for various indications [31], multiple professional organizations, including the American College of Radiology (ACR) and the American College of Cardiology (ACC), recently worked together to establish appropriateness criteria for both cardiac CT and MRI [6]. We recommend these criteria be used as a resource in practice for determining the appropriateness of these examinations. Recently, the ACR and the North American Society for Cardiovascular Imaging (NASCI) together published a white paper on the structured reporting of coronary CTA [32]. Efforts from professional societies to standardize various facets of cardiac imaging continue to increase [33, 34].

A Structured Cardiac CT Report

Our current comprehensive cardiac report is composed of clinical indications for the examination, a description of examination technique and imaging findings, and a final
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In our reports, we aim to explicitly describe the cardiac CT protocol used. We prefer to document all pharmaceutical agents used for heart rate and rhythm control (β-blockers, calcium blockers) and sublingual nitroglycerin used for temporary coronary artery dilatation, including the dose, timing, and route of administration. We also mention the heart rate and rhythm during the acquisition because of their impact on the accuracy of coronary CTA.

Generally, for a typical coronary CTA examination, the prescribed scan range extends from the angle of the carina to below the cardiac apex; for patients with coronary artery bypass grafts (CABGs) or who are having a combined coronary artery and thoracic aorta CT evaluation, the cranial extent of the scan zone is shifted superiorly to include the origins of the subclavian and internal mammary arteries. The method used to determine the scan delay time from the beginning of the IV contrast bolus is specified, whether it is a region of interest (ROI)–based trigger or a timing bolus performed with an ROI placed at the aortic root.

With respect to IV contrast administration, the type, concentration, quantity, rate, and route of administration, as well as canula size, are usually included. In our reports, we also specify the format of the IV contrast bolus used—specifically, whether a biphasic or a triphasic technique is used. A biphasic technique uses saline as the second phase of the bolus, immediately after the contrast injection, to completely wash out contrast material from the right heart chambers and to eliminate streak artifacts across the deep right atrioventricular groove in which the right coronary artery (RCA) sits. In a triphasic bolus, contrast material is followed by a mixture of saline and contrast material, so that there is some visualization of the morphology of the right heart chamber. For example, “80 mL of low-osmolar IV contrast material (370 mg I/mL of iodine concentration) was administered at 5 mL/s via a 20-gauge canula placed in the right antecubital fossa using a triphasic technique.” Right upper extremity venous access is preferred to avoid dense contrast material pooling in the left brachiocephalic vein and resulting in streak artifacts that could potentially obscure aortic arch anatomy, great vessel origins, and internal mammary artery grafs when scanning a CABG patient; this is less important if the scan range is confined to the native coronary arteries.

The type of ECG gating is also specified, including prospective ECG triggering for the calcium score acquisition and either prospective ECG triggering or retrospective gating for coronary CTA. Radiation dose-reduction measures used, including tube current modulation techniques, are also mentioned in our reports. Typically, in patients with a fixed R-R interval, tube current modulation is used, with the mA being reduced at the phases of the R-R interval that are generally not used for viewing the coronary arteries. In patients with a normal stable sinus rhythm and a heart rate of 65 beats per minute or lower, we acquire images only at the LV end-diastole during the cardiac cycle. This technique significantly reduces the radiation dose without compromising image quality, but it sacrifices the dynamic cardiac functional data. LV end-diastole is when there is relatively little motion and the greatest coronary artery blood flow, when the coronary arteries are usually the most optimally visualized. LV end-systole is the second relatively motion-free part of the cardiac cycle and may be used when LV end-diastole is insufficient, particularly for evaluation of the vertical portions of the RCA and left circumflex (LCX) coronary artery.

The computer workstation and the software version used to review the images may also be documented. If any specific quantification software is used to evaluate degree of coronary artery stenosis and plaque characterization, that may also be stated for the reader to understand the reliability of the results. We mention the use of advanced image postprocessing, such as creation of long- and short-axis multplanar reformations (MPRs), curved MPRs, and volume-rendered images for coronary artery assessment. We also describe quantitative and qualitative functional analysis of the LV using dynamic images in standard cardiac viewing planes, aortic valve anatomy, and, if performed, measurements of the areas of aortic valve stenosis and regurgitant orifices.

CT Calcium Score

**Background and Rationale**

Calcium scoring with CT has been in use for more than 20 years. This noninvasive acquisition does not use IV contrast material and is performed at a relatively low radiation dose compared with coronary CTA. It is used to detect and quantify coronary artery calcification (CAC) [35]. CAC is an established marker of atherosclerosis [36]. Amorphous hydroxyapatite deposits advance to differentiation of cells in the vessel wall to osteoblasts [37]. Although CAC is a specific indicator of the presence of coronary artery atherosclerosis, it represents only the calcified or healed plaque, not the full burden of plaque. CAC is estimated to represent approximately 10–20% of the total atherosclerotic plaque burden [38]. Patients who have CAC are more likely to have noncalcified plaque that is prone to rupture, leading to acute thrombosis, than patients without CAC [38]. CAC is a predictor of coronary events, myocardial infarction, and death [39]. Despite extensive research, the clinical indications and usefulness of calcium scoring have remained controversial.

CAC scoring was developed and used initially exclusively with EBCT scanners and validated with both radiologic–histopathologic correlation and multiple population-based studies [36, 40]. EBCT enabled ultrafast scanning of the heart using an electron beam and a stationary tungsten target. Examinations were acquired at 50 or 100 milliseconds per slice, with nonoverlapping 3- to 5-mm slices, and a fixed mAs (≈ 60–65 mAs) with prospective ECG triggering at one selected point in the R-R interval—usually end-diastole—to eliminate cardiac motion and blurring [38, 41]. Because EBCT scanners have limited clinical applications, they are not widely used today. With advances in MDCT technology, MDCT has become the primary CT platform for CT studies of CAC [42].

**Calcium Scoring on MDCT**

**Technique**—MDCT scanners with 4 or more detectors are recommended, with temporal resolution of 500 milliseconds or less [35]. Examinations are performed in the craniocaudal direction to cover the heart from the pulmonary trunk through the apex. The CT table is advanced in a steplike axial fashion. If a 16-MDCT scanner is used, scan duration is approximately 6–10 seconds; if all 16 detectors are used, collimation is either 0.5–0.75 mm width or 1.0–1.5 mm width. The suggested mA is 100, which may be reduced to as little as 55 mA [43]. When using 64-MDCT scanners, generally the gantry rotation time is 0.35 seconds, collimation is 64 × 0.625 mm, and reconstructed slice thickness is set at 2.5 mm, although there may be variations in technique depending on the CT manufacturer. As with EBCT,
prospective ECG triggering is used, with a radiation dose of approximately 1.5 mSv for men and 1.8 mSv for women [44]. Few articles report coronary calcium scoring using the current 64-MDCT scanners [45–48].

Postprocessing and calcium quantification—The calcium score is generated using software specifically designed for this purpose (Fig. 1). Semiquantitative scores are based on a section-by-section analysis of the CT images [49]. There are three scoring methods: the Agatston-Janowitz score, the volume score, and the mass score. The Agatston-Janowitz score was the initial method for calcium quantification and is the most widely used. To be included in the Agatston-Janowitz score, CAC must reach a threshold of 130 HU and cover an area of at least 1 mm²; calcifications that are lower in attenuation or smaller in size are not included in the score. The score of each calcification is calculated by multiplying the area of the CAC by its attenuation-weighting factor based on the highest HU value of the CAC, a score ranging from 1 to 4. A vessel score is the sum of all CAC scores from that vessel, and the total calcium score is the total of all CAC scores from all vessels [49]. This method has been in use the longest, and its prognostic implications have been the most studied, but it has several limitations. First, it was developed for EBCT and must be modified for MDCT. It is often reported on MDCT as the Agatston score equivalent. Second, the measurement is nonlinear because of the attenuation-weighting factor. And third, there is high interscan variability because of partial volume averaging effect and dependence on slice thickness and spacing [50]. In the mass method, pixel volume measuring 130 HU or more is multiplied by its attenuation in Hounsfield units, and the total calculated value is divided by 100 [52]. The volume and mass calcium scoring methods are less variable than the Agatston-Janowitz method [50].

Clinical Indications and Implications of the CAC
Calcium scoring with CT has been extensively tested for reliability and validity. A recently published updated clinical expert consensus document by the ACC and the American Heart Association (AHA) lists the recommended clinical indications for calcium scoring [42] (Appendix 4). Calcium scoring is not recommended in asymptomatic patients at high or low risk for CAD because it does not affect medical management and decision making [42]. Because the clinical outcome of plaque progression, its relationship to quantifiable stenosis, and the effect of modifying therapy on plaque progression are unknown, plaque follow-up with calcium scoring is not recommended.

Large focal calcifications significantly impair evaluation of the underlying lumen in coronary CTA, whereas diffusely scattered small calcifications do not. Significant obstructive coronary artery stenosis may be unrecognized in plaque having an Agatston-Janowitz calcium score of 400 or more [53]. Few researchers have attempted to define the impact of coronary calcium on the accuracy of coronary CTA [54–56].

Calcium scoring quantifies the calcified plaque alone. It does not directly visualize the vessel lumen, does not provide an estimate of coronary artery stenosis, and does not detect noncalcified plaque. The importance of CAC to an individual is reported as the percentile rank by sex, based on large cohorts of asymptomatic individuals who have undergone CAC assessment. A calcium score of 0 implies a low probability for significant obstructive CAD and future cardiac events [42]. However, it does not mean that a patient has no noncalcified or unstable plaque or that the probability of a future coronary event is 0 [57]. A positive calcium score correlates with the amount of plaque and is an independent predictor of obstructive CAD [58]. The higher the calcium score, the greater the amount of plaque and the higher the relative risk for cardiac events [59]. The presence of any measurable calcium increases the risk of a cardiac event in 3–5 years by nearly 4 times [42]. Although a positive score is a specific marker for the presence of CAD and has a high negative predictive value of 86–90% for obstructive coronary disease, it is not specific for obstructive CAD [35].

Normal Coronary Artery Anatomy
Evaluation of the coronary arteries begins with an axial review of their origin and proximal course. There are three sinuses of Valsalva, the right sinus of Valsalva or the anterior sinus, the left sinus of Valsalva or the posterior sinus, and the noncoronary sinus [60] (Fig. 2). The RCA and the left main coronary artery (LM) arise from their respective aortic sinuses of Valsalva. On axial images, the LM arises at a level that is cephalad to the RCA.

Fig. 2—48-year-old man with chest pain, elevated cardiac enzymes, and normal ECG. Axial maximum-intensity-projection CT image of aortic root shows origin of right coronary artery (straight arrow) from right coronary sinus and left main coronary artery (curved arrow) from left coronary sinus. Arrowhead indicates noncoronary sinus. RA = right atrium, LA = left atrium, RVOT = right ventricular outflow tract.
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Right Coronary Artery
The RCA (Figs. 2, 3, and 4A) courses anteriorly and laterally from its ostium at the right sinus of Valsalva and runs in the right atrioventricular groove, curving posteriorly at the acute margin of the right ventricle (RV) and bifurcating into the posterior descending artery (PDA) and the posterolateral LV branches at the crux of the heart. The RCA supplies the RV free wall. The proximal branches of the RCA are the conus and sinoatrial branches. The conus branch arises from the RCA in half of the population and directly from the aortic root in the other half. The sinoatrial nodal branch arises from the RCA in 60% of people and from the LCX in 40%. The other branches of the RCA include the acute marginal branches and the atrioventricular nodal branch. The PDA runs in the posterior interventricular groove and supplies the posterior third of the septum. The posterolateral LV branches supply the posterior surface of the LV. The RCA is divided into proximal, mid, and distal portions, with the proximal portion extending from the origin to the acute marginal origin, the mid portion extending from the acute marginal origin to the horizontal portion in the posterior right atrioventricular groove, and the distal portion extending beyond that.

Left Main and Left Anterior Descending Coronary Arteries
The LM arises from the left sinus of Valsalva and divides into its two main branches, the left anterior descending (LAD) and LCX coronary arteries (Figs. 2 and 5A). The LM may be short or long, varying in length from 5 to 20 mm [61]. Occasionally, the LM trifurcates, with the middle branch known as the ramus intermedius (Fig. 5B). The LAD courses anteriorly and inferiorly in the anterior interventricular groove to the apex of the heart, giving rise to septal perforators and diagonals. The septal perforators run perpendicular to the LAD and supply the anterior two thirds of the septum. The diagonals, of which there may be up to six, are numbered sequentially as they arise (D1, D2, and so forth). The diagonals run on the epicardial surface of the heart and supply the anterolateral portion of the LV. The LAD has proximal, mid, and distal portions. The proximal portion runs from the origin to the first septal perforator or first diagonal, the mid portion runs from there to the second diagonal, and the distal portion is distal to the second diagonal origin.

Left Circumflex Artery
The LCX runs along the left atrioventricular groove and in 80–85% of the population terminates at the obtuse margin of the heart after giving rise to the first obtuse marginal (OM1) branch (Figs. 4B and 5A). The LCX supplies the lateral aspect of the LV. The primary branches of the LCX are the OM arter-

Fig. 3—47-year-old woman with hyperlipidemia and hypertension. Volume-rendered image of right lateral view of heart created from IV contrast-enhanced ECG-gated coronary CT angiography image shows right coronary artery (curved arrow) coursing in right atrioventricular groove. Right lateral surface of right ventricle is perfused by acute marginal branches 1 (straight arrow) and 2 (arrowhead).

Fig. 4—Volume-rendered images of posterior view of heart of three patients in whom posterior descending artery (PDA) (arrowhead) and posterolateral left ventricular (LV) branches (straight arrows) define dominant patterns of coronary circulation. A, Image in 52-year-old woman shows both PDA and posterolateral LV branches originate from distal right coronary artery (RCA) (curved arrow), suggesting right coronary circulation dominance. B, Image in 68-year-old man shows PDA and posterolateral LV branches arise from distal left circumflex coronary artery (LCX) (curved arrow), suggesting left coronary circulation dominance. C, Image in 50-year-old man shows PDA and posterolateral LV branches originate from RCA (curved arrow) and LCX, respectively, suggesting codominance (balanced dominance) of coronary circulation.
ies, numbered sequentially as they arise (OM1, OM2, and so forth). The LCX may also continue posteriorly to the crux of the heart; it gives rise to the PDA, the atrioventricular nodal branch, and the posterolateral LV branches. The LCX is divided into proximal and distal portions in relation to the major OM branch origin.

The dominance of the coronary circulation is determined by the circulation that gives rise to the atrioventricular nodal artery, the PDA, and the posterolateral LV branches (Fig. 4). Eighty to 85% of the population have right coronary circulation dominance, 8–10% have left coronary dominance, and 7–8% have codominance (balanced dominance), in which the PDA and the posterolateral LV branches originate respectively from the RCA and LCX (Fig. 4).

On coronary CTA, coronary artery segments can be reported in a standardized fashion using the widely followed AHA coronary artery segmentation model defining 15 segments in which the proximal, mid, and distal portions of the RCA are respectively segments 1–3; the PDA is segment 4; the LM is segment 5; the proximal, mid, and distal LAD are segments 6–8; the D1 and D2 are segments 9 and 10; the proximal and distal LCX are segments 11 and 13; the OM artery is segment 12; the posterolateral LV branch is segment 14; and the PDA, if present as a branch of the LCX, is segment 15 [62].

Anomalous Coronary Artery Anatomy

Anomalies of the coronary arteries are rare, occurring in 0.3–5.6% of the population, and are often an incidental finding in asymptomatic patients [63]. Most coronary anomalies do not have an adverse clinical outcome; however, the origin of a coronary artery from the opposite sinus of Valsalva, or a coronary artery with an interarterial course of the proximal segment between the aortic root and the RV outflow tract or pulmonary artery can be potentially fatal. Hence, an interarterial course is considered malignant, whereas the retroaortic and prepulmonic courses are considered either benign or non-malignant. However, it is important to recognize the retroaortic course in patients who may potentially undergo surgery of the aortic root or the ascending aorta (Figs. 6 and 7).

Accurate diagnosis of a coronary artery anomaly is important, particularly in young athletes or in young military recruits, because up to one third of cardiac-related deaths in that age group are related to such anomalies [64]. For many years the diagnosis of coronary anomalies was made on invasive catheter coronary angiography or at autopsy. However, the course of anomalous coronary arteries is often difficult to determine at invasive catheter-based angiography. The coronary circulation should be evaluated systematically, starting from the aortic root and proceeding distally...

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**Fig. 5**—Volume-rendered images of anterior view of heart in two patients in left anterior oblique projection showing left coronary circulation.  
**A,** Image in 58-year-old man with multiple cardiac ischemic risk factors who presented with chest pain shows left main artery (curved arrow), left anterior descending (LAD) artery (arrowhead), and left circumflex artery (straight arrow). LAD also gives rise to diagonal branches.  
**B,** Image in 70-year-old woman shows ramus intermedius branch (arrow).

**Fig. 6**—Malignant course of coronary artery.  
**A,** Oblique axial maximum-intensity-projection image of aortic root in 14-year-old competitive male athlete with exertional chest pain and palpitations shows right coronary artery (curved arrow) arising from left sinus of Valsalva (straight arrow) and coursing in malignant fashion between right coronary sinus (arrowhead) and right ventricular outflow tract (RVOT). This anomalous coronary course was surgically corrected.  
**B,** Axial contrast-enhanced image at aortic root in 30-year-old woman shows left main coronary artery (arrowhead) arising from right coronary sinus (arrow) and coursing between RVOT and aortic root in malignant fashion.
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correlation better with the depth than with the length of the submyocardial segment [69]. Myocardial bridging may have a physiologic limitation in coronary blood flow [70]; however, its significance remains debatable [68].

Summary

In conclusion, we have illustrated our comprehensive approach to reporting coronary CTA findings that includes patient preparation, acquisition technique, coronary calcium scoring, and normal and anomalous coronary artery anatomy. This article may provide fundamental information and improve the understanding of coronary CTA reporting pertaining to the background of CT coronary imaging, the calcium scoring technique, clinical indications for and implications of calcium scoring, coronary artery anatomy, and an introduction to the coronary artery anomalies and their significance. In part 2 of this article [71], we discuss coronary artery atherosclerotic disease and cardiac function assessment.

References

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Appendices follow on next page
APPENDIX 1: Our Structured Cardiac CT Report Template

CT Coronary Calcium Scoring:
- LMA = ( ), LAD = ( ), LCX = ( ), RCA = ( ), PDA = ( )
- Total calcium score = ( ) using the AJ-130 method and ( ) volume score
- ( ) percentile rank for age and gender, meaning that ( )% of patients of the same age and gender will have a higher score

Coronary CT Angiography:
- Coronary arterial dominance (right, left, codominant)
- Left main, LAD and diagonals, LCX and obtuse marginal, RCA and posterior descending, ramus intermedius, and any anatomic variants
- Quantification of stenoses (mild < 50%/mod 50–70%/severe > 70%)

Cardiac Structure, Morphology, and Function:
- Evaluation of short- and long-axis LV cines demonstrates (normal regional left ventricular wall motion) or (hypokinesis, akinesis, or dyskinesis; specify wall or if global)
- LV functional parameters: end-diastolic volume, end-systolic volume, stroke volume, cardiac output, ejection fraction, LV mass

Summary:
1. Total coronary calcium score = ( ).
2. (Normal coronary arteries or specify abnormality).
3. (Normal or abnormal) left ventricular wall motion. LV ejection fraction = ( ).
4. (Normal or abnormal) cardiac chamber size.

Note—LMA = left main artery, LAD = left anterior descending artery, LCX = left circumflex artery, RCA = right coronary artery, PDA = posterior descending artery, AJ-130 method = Agatston-Janowitz score of 130 HU, mod = moderate, LV = left ventricle.

APPENDIX 2: Coronary CT Angiography, Technical Details
- Pharmaceutical agents (quantity, route, rate of administration)
- Cardiac rate, rhythm, scan coverage zone
- Scan delay time method, biphasic/triphasic bolus technique
- IV contrast: name, concentration, quantity, rate, and route
- Prospective/retrospective ECG gating techniques
- Radiation dose-reduction measures
- Computer workstation viewing software

Appendices continue on next page
APPENDIX 3: Coronary CT Findings

Coronary Arteries:
- Calcium score with age/sex percentile rank
- Coronary artery origin, course, and dominance
- Atherosclerosis (plaque composition, luminal narrowing)

Noncoronary Cardiovascular Structures:
- Quantitative evaluation of left ventricle (LV)
  - Stroke volume (SV), ejection fraction (EF), cardiac output (CO), end-diastolic and end-systolic volumes (EDV and ESV)
- Qualitative evaluation of LV wall motion
- Cardiac chamber size and morphology (LV mass)
- Cardiac valve morphology
- Pericardium
- Other cardiovascular structures
  - Aorta, pulmonary artery tree, and pulmonary veins
  - Superior and inferior venae cavae
  - Coronary veins

Noncardiovascular Structures:
- Lungs, pleura, airways
- Esophagus, mediastinal and hilar lymph nodes
- Diaphragm, body wall including osseous structures
- Upper abdominal contents (organs, bowel loops, mesentery)

APPENDIX 4: Recommended Use for Calcium Scoring CT

Asymptomatic Patients:
- Intermediate risk for coronary artery disease; total calcium score > 400 raises risk to high, justifying lifestyle modification and pharmacological therapy maximization

Symptomatic Patients:
- A screening tool before performing invasive procedures
- Functional testing (such as stress test) is not possible or is inconclusive

Note—Adapted from [42].

FOR YOUR INFORMATION
- The reader’s attention is directed to part 2 of this article, titled “Anatomy and Terminology for the Interpretation and Reporting of Cardiac MDCT: Part 2, CT Angiography, Cardiac Function Assessment, and Noncoronary and Extracardiac Findings,” which appears on page 584.
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