Technical and Personnel Requirements

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Abstract

In this chapter, the requirements for setting up a cardiac CT practice are summarized. At least a 64-row CT scanner should be present from a technical perspective, and the personnel needs to be adequately und continuously trained in performing, reconstructing, and reading cardiac CT datasets.

2.1 Technical Requirements

Noninvasive coronary angiography is the major clinical application of computed tomography (CT) that requires very high spatial and temporal resolution. Thus, CT scanners with multiple detector rows (multislice CT), short gantry rotation times, and thin-slice collimation are essential for establishing a successful cardiac CT practice. Because 64-row CT is relevantly superior to 16-row CT in terms of image quality and diagnostic accuracy, at least 64-row technology should be used for noninvasive coronary angiography (**List 2.1**). CT with 64-row technology not only increases the quality of the images (**Figs.** 2.1, 2.2 and 2.3) but also improves the workflow because scanning and breath-hold times are shorter (**Table** 2.1). Even greater improvements can be achieved with imaging during a single heartbeat (**Table** 2.1 and **Figs.** 2.2 and 2.3), which is feasible with 320-row volume CT and second-generation dual- source CT (Chaps. 9a and 9b). The shorter breath-hold time of 64-row CT and single-beat imaging is also very relevant for patients after coronary bypass grafting (**Fig.** 2.4, Chap. 12). The faster gantry rotation speed of recent CT scanners (**List 2.1**) improves temporal resolution and dramatically reduces the likelihood of relevant motion artifacts.

List 2.1. Technical requirements for cardiac CT

1. CT scanner with at least 64 simultaneous rows
2. CT scanner with a gantry rotation time of below 400 ms
3. Adaptive multisegment reconstruction or dual-source CT
4. ECG for gating or triggering[a] of acquisitions
5. Dual-head contrast agent injector for saline flush
6. Workstation with automatic curved multiplanar reformation and three-dimensional data segmentation and analysis capabilities

[a] This refers to the acquisition method: retrospective (ECG gating) or prospective (ECG triggering). See Chap. 7 for details on radiation exposure reduction using ECG triggering

Temporal resolution can be significantly improved by using two simultaneous X-ray sources (dual-source CT, Siemens) and adaptive multisegment reconstruction (Toshiba, Philips, and GE). We believe that one of these two approaches should be implemented on cardiac CT scanners to reduce the influence of heart rate on image quality (**List 2.1**).

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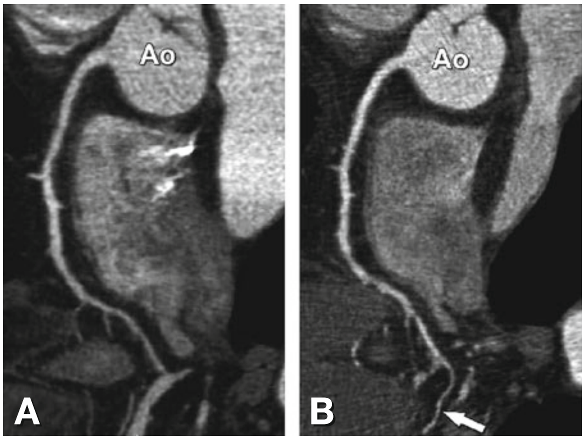

Fig. 2.1 Comparison of 16-row (**Panel A**) and 64-row CT coronary angiography (**Panel B**) of the right coronary artery (curved multiplanar reformation) in a 61-year-old male patient. 64-row CT shows longer vessel segments, especially in the periphery (*arrow*). This enhanced performance can be explained by fewer motion artifacts (due to breathing, extrasystoles, or variations in the length of the cardiac cycle) and the better contrast between arteries and veins resulting from the faster scan and consequently better depiction of the arterial phase. The improved depiction of the arterial phase using 64-row CT is also demonstrated in **Fig.** 2.2. **Panel B** also illustrates the slightly higher image noise with 64-row CT, which can be compensated for by the better depiction of the arterial phase and the higher intravascular density. *Ao* aorta

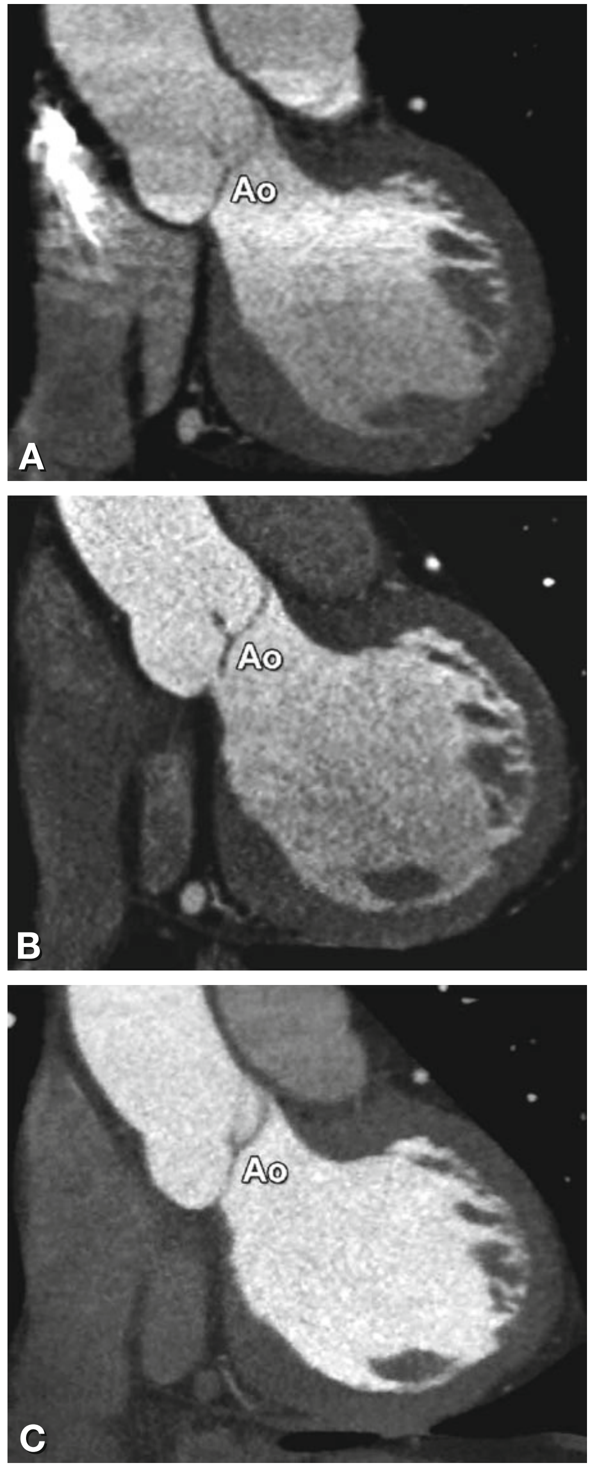

Fig. 2.2 The improved depiction of the arterial phase using 64-row CT (**Panel B**) and even further using 320-row CT (**Panel C**) when compared with 16-row CT (**Panel A**) is illustrated by a double oblique coronal slice along the left ventricular outflow tract, with the aortic valve nicely depicted (*Ao*). In the craniocaudal direction, the density in the aorta and left ventricle shows less variation and decline when 64 simultaneous detector rows are used (**Panel C**) and almost no difference with 320-row CT acquired during a single heartbeat. Use of 64- and 320-row CT thus improves image quality and facilitates the application of automatic coronary vessel and cardiac function analysis tools

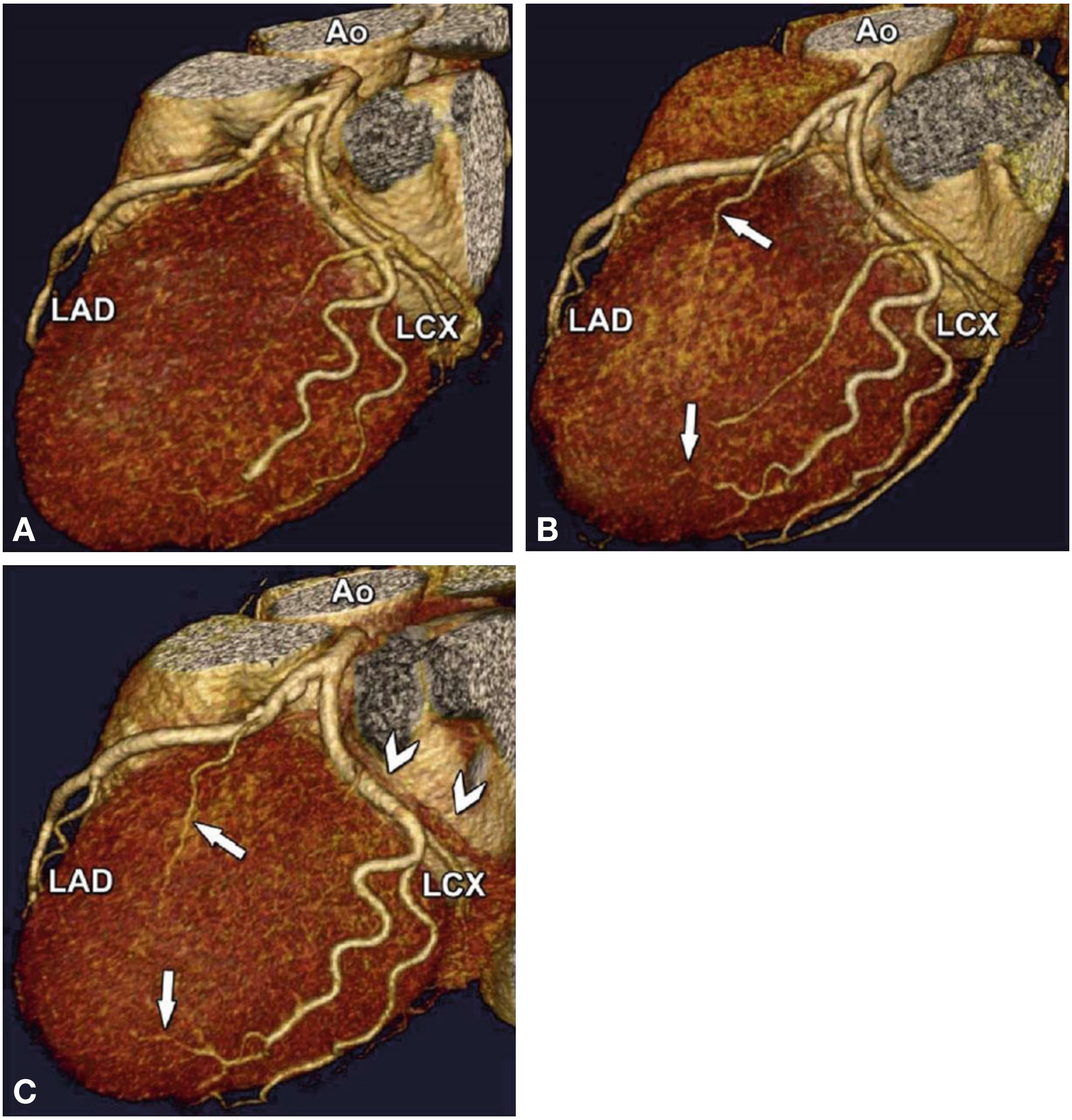

Fig. 2.3 Example illustrating the improved depiction of distal coronary artery branches using 64-row (**Panel B**) and 320-row CT (**Panel C**) in a 58-year-old female patient. Three-dimensional volume-rendered reconstructions of the left coronary artery with the left anterior descending (*LAD*) and left circumflex coronary artery (*LCX*) examined using 16-row (**Panel A**), 64-row (**Panel B**), and 320-row CT coronary angiography (**Panel C**). Note the improved depiction of smaller side branches with the 64-row (*arrows* in **Panel B**) and 320-row technology (*arrows* in **Panel C**) when compared with the same segments in 16-row CT (**Panel A**). Also, there is best depiction of the arterial phase (with less venous overlap, *arrowheads* in **Panel C**) using 320-row CT. Single-beat imaging using 320-row CT or second-generation dual-source CT with a fast prospective spiral also greatly reduces radiation exposure (Chap. 7). *Ao* aorta

Table 2.1 Typical characteristics of 16- and 64-row as well as single-heartbeat CT scanners

	16-row	64-row	Single heart beat CT[a]
Slice collimation			
Coronary arteries	0.5–0.75 mm	0.5–0.75 mm	0.5–0.6 mm
Coronary bypass grafts	0.5–1.25 mm	0.5–0.75 mm	0.5–0.6 mm
Gantry rotation time			
Coronary angiography	0.4–0.6 s	0.27–0.4 s	0.28–0.35 s
Scan length			
Coronary arteries	9–13 cm	Increase by 15%[b]	9–13 cm
Coronary bypass grafts	12.5–22 cm	Increased by 5–10%	12.5–22 cm[c]
Effective radiation dose			
Coronary arteries	5–15 mSv	10–20 mSv[d]	1–5 mSv
Coronary bypass grafts	10–30 mSv	20–40 mSv[d]	2–10 mSv
Contrast-to-noise ratio			
Coronary angiography	15–25	Similar	Similar
Vessel lengths free of motion			
Coronary angiography		Improved by 10–30%[e]	Further improvements expected
Breath-hold time[f]			
Coronary arteries	25–30 s	8–12 s	3 s
Coronary bypass grafts	40–50 s	12–15 s	5 s
Contrast agent amount			
Coronary arteries	90–130 ml	60–90 ml	40–70 ml
Coronary bypass grafts	130–160 ml	80–110 ml	50–80 ml

[a] CT of the heart during a single beat can be performed using 320-row volume CT (Chap. 9a) and second- or third- generation dual-source CT with a fast spiral acquisition (Chap. 9b)

[b] This increase is due to the larger overranging effect of 64-row CT, which in turn also increases radiation exposure by 15%

[c] Bypass grafts are scanned with 320-row CT in two heartbeats and with dual-source CT in the caudocranial direction with the proximal parts of the bypass grafts covered during the next R-wave and early systole of the next beat

[d] The values given here are for retrospectively acquired data. The increase in effective dose with 64-row CT can be explained by the larger overranging effect, the fact that scanning cannot be stopped as abruptly once the lower border of the heart has been reached because of the faster table speed, and the higher mA settings necessary (because of the increased scattered radiation and noise with 64-row CT). Using prospectively acquired data with 64-row CT, effective dose can be drastically reduced to below 5 mSv in nearly all patients with stable and low heart rates (<65 beats per minute). See Chap. 7

[e] The increase in the visible vessel length free of motion that can be obtained for the three coronary arteries with 64-row CT scanners is approximately 10% for the left anterior descending, 20% for the left circumflex, and 30% for the right coronary. Most notably, in more than one-third of all cases, the length of the right coronary free of motion is increased by more than 5 cm when 64-row CT is used

[f] This includes a 2–3 s wait period after the breathing command before scanning to assure normalization of heart rate after inspiration

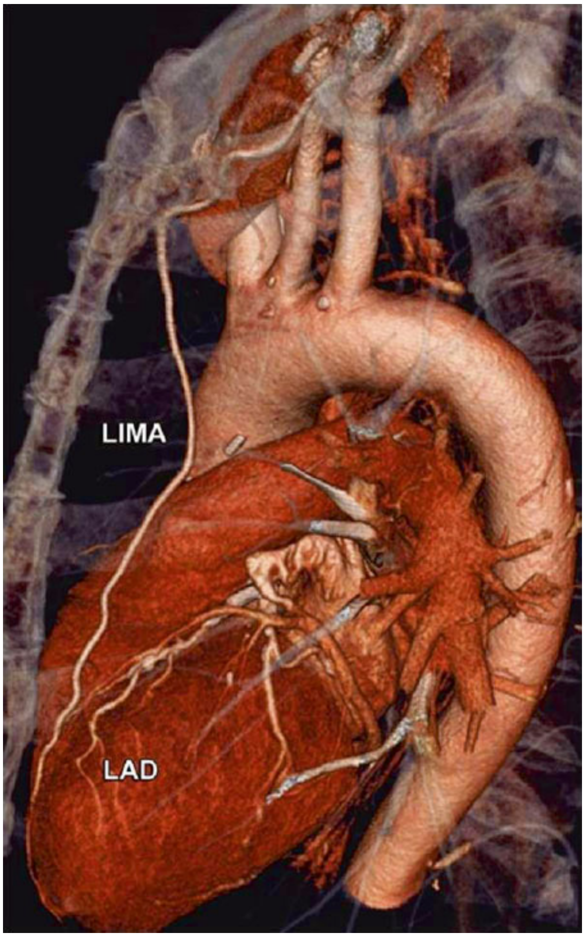

Fig. 2.4 Arterial bypass graft (left internal mammary artery, *LIMA*), which extends all the way down to the LAD and was scanned in less than 15 s, using a 64-row CT scanner. With this technology, preoxygenation is no longer necessary for bypass imaging. With 16-row technology, the scanning took an average of 40–50 s, and preoxygenation was almost always required. Note that CT nicely depicts the distance between the sternum and coronary bypass graft, which can be of relevance if repeat cardiac surgery is considered. Bypass imaging time can be further shortened with 320-row CT and second-generation dual-source CT (**Table 2.1**)

In addition to these technical improvements, beta blocker administration should be used whenever possible to lower the heart rate to below approximately 60 beats per min, because slowing the heart rate to this level further improves both the image quality and the diagnostic accuracy (Chaps. 6 and 8) while also reducing radiation exposure because ECG triggering can be used (Chap. 7). Finally, an ECG, a dual-head contrast agent injector, and an automatic three-dimensional analysis workstation are required for cardiac CT (**List 2.1**).

2.2 Purchasing a Scanner

The purchase costs of CT scanners still differ enormously. For applications other than cardiac imaging, 16-row CT scanners are clearly sufficient to answer the vast majority of clinical questions. For cardiac applications, however, at least 64-row technology is clearly needed. The decision to purchase a scanner from any particular manufacturer not only depends on its meeting the relevant technical criteria, such as those mentioned earlier, but will definitely also be influenced by local pricing policies and, more important, by the quality of the maintenance and service support (**List 2.2**). How to perform cardiac CT exams using scanners from the four main vendors is explained in Chaps. 9a, 9b, 9c and 9d.

List 2.2. Factors to consider in deciding to purchase a particular CT sanner

1. Local situation and mixture of different examination types
2. Quality of technical and maintenance support
3. Availability of high temporal and spatial resolution
4. Quality and durability of the application support
5. Integration into existing picture archiving and communication systems
6. Local pricing policies

Multislice CT has a variety of other applications in addition to cardiac imaging, and CT scanners used solely for cardiac applications are very unlikely to reach the break-even point. Thus, we believe that a mixture of different CT applications is a prerequisite for clinical and economic success. In the USA, the Center for Medicare and Medicaid Services (CMS) decided after an extensive review that no Medicare national coverage of coronary CT angiography was appropriate in 2008. In the decision memo, it is concluded that no adequately powered study has established that improved health outcomes can be causally attributed to coronary CT angiography for any well-defined clinical indication. Thus, coverage will be determined by local contractors through the local coverage determination process or case-by-case adjudication. The local coverage decisions are variable in extent. Effective January 1, 2010, the American Medical Association (AMA) released the new Current Procedural Terminology (CPT) Category I codes for cardiac CT with four new codes. These replace the previous Category III CPT codes for cardiac CT, which listed cardiac CT examinations as "emerging technology." Coverage is a local issue that is quickly changing and needs to be looked into before setting up a cardiac CT practice anywhere. Chapter 4 discusses cardiac CT in clinical practice and Chap. 5 presents clinically most relevant indications for cardiac CT. In some countries, such as Japan, there is national coverage of cardiac CT, whereas in others such as Germany cardiac CT is reimbursed as a chest CT only.

2.3 Personnel Requirements

Having well-trained technicians who are knowledgeable in cardiac CT applications is a prerequisite for success (**List 2.3**). It is better to have a limited number of specialized technicians who perform cardiac CT than to have all technicians perform this test. On the one hand, having specialized staff members can ensure a consistently high level of image quality, and these experienced technicians can assist in further educating other coworkers about the entire scanning and reconstruction procedure. On the other hand, if more technicians are involved in performing cardiac CT, coronary CT angiography can easily be offered at night; doing so, however, also requires a physician trained in reading the images 24 by 7. What we consider most helpful in terms of training is to give constant feedback to the technicians about good as well as bad examinations. This approach ensures that a high level of quality is maintained, and small mistakes are prevented from creeping in. Moreover, providing positive feedback about high-quality examinations is very motivating, and sufficient hands-on training should be provided to anyone involved in performing or reading cardiac CT scans.

List 2.3. Personnel requirements for cardiac CT

1. Well-trained and experienced CT technicians
2. Physician knowledgeable in CT and radiation exposure
3. Physician knowledgeable in cardiac anatomy and pathophysiology
4. Team focused on quality assurance

There are two major prerequisites for physicians, in addition to good anatomical, technical (incl. radiation issues), and clinical knowledge: (1) a clear understanding of the entire examination procedure, and (2) the ability to independently interpret three-dimensional cardiac CT datasets on workstations.

Chapters 6 and 8 discuss how to prepare the patient for cardiac CT and how to perform the procedure. Being present during examinations is the key to understanding the work of the technicians and the special requirements of cardiac CT. It is also enlightening for physicians to perform examinations themselves, because doing so can yield important insights into the procedural steps and problems that can be encountered during scanning. This hands-on training also strengthens the position of the physician as an educator of other physicians or technicians. In larger centers, it is good to identify two to three doctors who will be considered the primary contacts for cardiac CT imaging for the technicians as well as the referring physicians.

2.3.1 Hands-on Courses, Learning Curve, and Accreditation

Competence in image interpretation is best achieved by correlating conventional coronary angiograms with CT angiography results. How to read and interpret cardiac CT scans is explained in Chap. 10. To understand and gain skill in using the workstations, physicians should practice operating them without time pressure. The time necessary to feel comfortable with the workstations will depend on an individual's general computer skills, but 2–4 continuous weeks should be sufficient, and attending one of the true hands-on courses is a good way to begin the learning process. Such courses should ideally offer direct comparison of CT findings (on interactive workstations) with conventional coronary angiography and/or the results of cardiac stress tests. This is the only way of acquiring a thorough understanding of coronary and cardiac pathology. Good cardiac CT courses and fellowships also offer active participation in patient preparation and scanning. Nevertheless, the learning curve for centers with some prior experience has been shown to last at least 6 months before the diagnostic accuracy stabilizes, and the learning curve of individuals with little prior exposure is considerable (at least about 12 months).

Moreover, learning does not stop after a few weeks of intensive familiarization with the workstations or a short course: Even in a team of experienced readers, certain coronary lesions will sometimes be misinterpreted (over- called or even overlooked). Thus, continuous learning efforts with comparison of CT to the invasive coronary angiography findings, e.g., in joint interdisciplinary conferences, are necessary to maintain high quality.

There is also a formal accreditation of the physicians' skills and knowledge. The American College of Radiology (ACR) and the American College of Cardiology (ACC) have established guidelines for assessing clinical competence in performing and interpreting cardiac CT. These guidelines play an increasing role in obtaining certification and claiming reimbursement in the US. Those outside the US may find it useful to study these guidelines as a basis for starting discussions about certification of cardiac CT readers and centers in their own countries.

In Germany, for instance, the law requires that every physician performing CT (of any organ) hold the *Fachkunde* ("technical qualification") for CT, which requires having conducted 1,000 examinations over a period of at least 12 months and participating in a course on radiation protection. Such regulations offer promise for reducing patient radiation exposure and they emphasize the relevance of the ongoing discussion on requirements for cardiac CT.

2.3.2 Guidelines of the ACR

Several ACR guidelines are relevant to coronary CT angiography. Most important is the "ACR Practice Guideline for the Performance and Interpretation of Cardiac Computed Tomography" (http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/CT_Cardiac.pdf). Other important guidelines are the "ACR Clinical Statement on Noninvasive Cardiac Imaging," "ACR Practice Guideline for the Performance and Interpretation of CT Angiography," and the "ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography." Later we briefly outline and discuss the recommendations arising from the guidelines that directly relate to coronary CT angiography.

The ACR defines cardiac CT as a chest CT performed primarily for the evaluation of the heart (including the cardiac chambers, valves, myocardium, aorta, central pulmonary vessels, pericardium, coronary arteries, and veins). However, noncardiac structures are included and must be evaluated by a trained physician. Trained physicians are defined in the "ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography" as board-certified radiologists who have interpreted and reported at least 100 CT examinations over each of the past 3 years and interpret and report at least 100 CT examinations per year to maintain

Table 2.2 ACR physician requirements for coronary CT angiography

	Not trained in general or thoracic CT	Board-certified radiologists[a]
CME (category I)	Completion of an ACGME approved training program in the specialty practiced 200 h in cardiac CT[b]	Training in cardiac CT in an ACGME approved training program 30 h in cardiac anatomy, physiology, pathology, and cardiac CT
Interpretation, reporting, and/or supervised review[c]	500 CT examinations[d]	50 contrast-enhanced cardiac CT examinations
Maintaining competence	75 contrast-enhanced cardiac CT examinations every 3 years 150 h of CME every 3 years	

ACGME Accreditation Council for Graduate Medical Education

[a] In addition, at least 100 CT examinations are required during each of the past 3 years, as also at least 100 CT examinations per year to maintain competence according to the ACR practice guideline for performing and interpreting diagnostic CT

[b] Including at least 30 h in cardiac anatomy, physiology, pathology, and cardiac CT

[c] Examinations (noncontrast examinations do not count) in a supervised environment during the past 3 years; supervising physician needs to meet the ACR requirements

[d] At least 100 must be a combination of thoracic CT or thoracic CT angiography (exclusive of calcium scoring exams). At least 50 contrast-enhanced cardiac CT examinations must also be included

competence. These physicians can achieve competence in the performance and interpretation of coronary CT angiography by at least 30 h of CME in cardiac anatomy, physiology, pathology, and cardiac CT, plus the interpretation, reporting, and/or supervised review of at least 50 cardiac CT examinations during the past 3 years (**Table** 2.2). Physicians who are not defined in this guideline as trained physicians in diagnostic CT can achieve competence in the performance and interpretation of coronary CT angiography by at least 200 h of CME in the performance and interpretation of cardiac CT, plus the interpretation, reporting, and/or supervised review of at least 500 chest CT examinations (including 50 cardiac CT examinations) during the past 3 years (**Table** 2.2). The ACR stresses that all physicians performing cardiac CT need to be knowledgeable about the administration, risks, and contraindications of beta blockers and nitroglycerin.

2.3.3 Guidelines of the ACC

The "ACC Clinical Competence Statement on Cardiac Imaging with Computed Tomography and Magnetic Resonance" (http://www.cbcct.org/resources/ CT_CMRcompetency.pdf) states that it is intended to be complementary to the recommendations of the ACR on noninvasive cardiac imaging. Cardiac CT is defined in this guideline as the imaging of anatomy, function, coronary calcium, noncalcified plaque, and congenital heart disease. The guideline defines three levels of competence in coronary CT angiography, of which two are relevant here. Level 2 allows independent performance and interpretation of cardiac CT and requires 8 weeks (each consisting of at least 35 h) of cumulative training in a clinical cardiac CT laboratory plus 150 contrast-enhanced and 50 noncontrast cardiac CT examinations. A physician willing to achieve level 2 competence needs to be physically present and involved in the acquisition and performance of 50 of the 150 contrast-enhanced cardiac CT examinations (**Table** 2.3). Level 3 allows serving as a director of an independent cardiac CT center and requires 6 months of cumulative training in a clinical cardiac CT laboratory plus 300 contrast-enhanced and 100 noncontrast cardiac CT examinations. A physician willing to achieve level 3 competence needs to be physically present and involved in the acquisition and performance of 100 of the 300 contrast-enhanced cardiac CT examinations (**Table** 2.3). An additional recommendation for "Training in Advanced Cardiovascular Imaging (Computed Tomography)" has been released by the ACC. The ACC stresses that all physicians performing cardiac CT need to be knowledgeable about radiation risks and noncardiac findings on coronary CT angiography. Interestingly, Pugliese et al. have recently shown that it may take more than 12 months of full-time training in cardiac CT for a novice to acquire moderate expertise and they conclude that the levels of training suggested by the ACC may thus be insufficient to become an independent practitioner of cardiac CT. However, the debate is ongoing and further recommendations are expected.

Table 2.3 ACC physician requirements for coronary CT angiography

	Level 2[a]	Level 3[b]
CME (category I)	20 h in cardiac CT	40 h in cardiac CT
Training[c]	8 weeks	6 months
Interpretation, reporting, and/or supervised review	50 noncontrast and 150 contrast- enhanced cardiac CT examinations[d]	100 noncontrast and 300 contrast-enhanced cardiac CT examinations[d]
Maintaining competence	50 contrast-enhanced cardiac CT examinations every year, 20 h of CME in cardiac CT every 3 years	100 contrast-enhanced cardiac CT examinations every year, 40 h of CME in cardiac CT every 3 years

[a] Allows independent performance and interpretation of cardiac CT

[b] Allows serving as a director of an independent cardiac CT center

[c] Training must be conducted under the supervision of a level 3 physician. Each week consists of at least 35 h. The time commitment does not go into effect until July 2010

[d] Physically present and involved in the acquisition, performance, and interpretation of 50 (level 2) or 100 (level 3) contrast-enhanced cardiac CT examinations. The noncontrast examinations can be performed in the same patients who undergo contrast-enhanced CT

Recommended Reading

Achenbach S, Chandrashekhar Y, Narula J (2008) Computed tomographic angiography and the Atlantic. JACC Cardiovasc Imaging 1:817–819

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Weinreb JC, Larson PA, Woodard PK et al (2005) ACR clinical statement on noninvasive cardiac imaging. J Am Coll Radiol 2:471–477

Further Recommended Websites

The ACR practice guideline for the performance and interpretation of cardiac CT (update of Jacobs et al.) can be accessed at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/CT_Cardiac.pdf

The guideline of the ACC (Budoff et al.) can be accessed at: http://content.onlinejacc.org/article.aspx?articleid=1136771

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