Canadian Cardiovascular Society/Canadian Association of Radiologists consensus training standards for cardiac computed tomography

Primary panel: Alan Brydie MBChB MRCP(UK) FRCR FRCPC[1], Benjamin JW Chow MD FRCPC FACC FASNC[2,3], Carole J Dennie MD FRCPC[3], Eric Larose DVM MD FRCPC FAHA[4], Jonathan A Leipsic MD FRCPC[5], Tej Sheth MD FRCPC[6]

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With the goal of optimizing patient care, standards for training in cardiac computed tomography have been developed collaboratively by the Canadian Association of Radiologists and the Canadian Cardiovascular Society. These standards apply to both radiologists and cardiologists.

Key Words: Cardiac CT; Guidelines; Training

Les normes de formation consensuelles de la Société canadienne de cardiologie et de l'Association canadienne des radiologistes à l'égard de la tomodensitométrie cardiaque

Dans l'intention d'optimiser les soins aux patients, l'Association canadienne des radiologistes et la Société canadienne de cardiologie ont préparé conjointement des normes de formation en tomodensitométrie cardiaque. Ces normes s'appliquent à la fois aux radiologistes et aux cardiologues.

Standards for training in cardiac computed tomography (CT) have been developed collaboratively by the Canadian Association of Radiologists and the Canadian Cardiovascular Society. These standards apply to both radiologists and cardiologists, with the mutual goal of optimizing patient care. The training standards pertain to the interpretation of cardiac CT and not to the interpretation of extracardiac findings. The Canadian Association of Radiologists/Canadian Cardiovascular Society working group recognizes the need for rigorous training because acquiring expertise in cardiac CT interpretation is a relatively slow process (1,2). Regular updates and revisions to these standards will continue to be developed in a collaborative manner. Competence is divided into three categories.

The working group is aware of other training guidelines recently published by various professional societies and has elected to use similar designations for levels of training. While the nomenclature is similar, the recommendations are different, and have been carefully reviewed and agreed on by consensus.

LEVEL 1 TRAINING

Level 1 training constitutes exposure to cardiac CT that is sufficient to understand the strengths and weaknesses of the modality, indications and contraindications. This level of training is not sufficient to independently interpret cardiac CT and generally applies to exposure to cardiac CT during residency training.

LEVEL 2 TRAINING

Level 2 training constitutes sufficient training for independent performance and interpretation of cardiac CT examinations. The components include acquisition of content knowledge, imaging training and maintenance of competence.

Content knowledge

The content knowledge suggested for cardiac CT is included in Appendix A. This knowledge is to be obtained through didactic teaching, courses or continuing medical education (CME).

Imaging training

Of a total of 150 cases of electrocardiogram (ECG)-gated contrast-enhanced thoracic CT:

- 75 cases are coronary CT angiography (CTA) studies that are directly acquired, reconstructed and interpreted by the trainee. Interpretation must be mentored by an expert cardiac CT reader with level 3 training, and a report must be generated by the trainee.
- 75 cases are gated contrast-enhanced thoracic CT studies that may include cardiac CT or other noncardiac thoracic CT studies. These may be directly acquired and interpreted or, in the case of cardiac CT, drawn from a case library or other teaching resource. Cardiologists will interpret cardiac CT studies. Radiologists may interpret cardiac or other gated thoracic CT studies. However, if noncardiac-gated thoracic CTs are chosen, these must be directly acquired.
- 25 cases must include a noncontrast CT for calcium scoring.
- 25 cases must be coronary CTA studies with correlation to invasive angiography. These may be acquired by the trainee or read from a case library. However, for cases obtained from a library, the invasive angiography and the original CTA dataset should be reviewed (not just preprepared three-dimensional [3D] reconstructions). The majority of the cases obtained from the library should be abnormal.

This interpretation must be satisfactory based on the judgment of the level 3 mentor.

This training is not sufficient to independently interpret studies pertaining to congenital heart disease.

Maintenance of competence

An ongoing case volume is required to ensure institutional (nurse, technologist) and physician competence in the performance of cardiac CT. Therefore, a minimum of 50 cases per reader per year is required to maintain competence. It is also essential that physicians participate in accredited CME programs to maintain their knowledge in the field.

LEVEL 3 TRAINING

Level 3 training constitutes expert training in cardiac CT that qualifies the trainee to run a cardiac CT program and serve as a local resource person in cardiac CT. Individuals with level 3 training will usually work in tertiary care centres or academic institutions in which there is active participation of both cardiologists and radiologists. The components include acquisition of content knowledge, imaging training and maintenance of competence. Level 3 training is not required to perform CTA, but physicians performing CTA with level 2 training should have access to a level 3 trained colleague, either in their own institution or in a tertiary referral centre. These recommendations and standards are meant to describe training and competency requirements for an institution-based practice with pre-established radiation protocols in place.

Content knowledge

Level 3 trained individuals should have a more detailed and in-depth mastery of the content knowledge outlined in Appendix A (including knowledge of CT imaging of congenital heart disease) than those with level 2 training.

Imaging training

Of a total of 300 cases of ECG-gated contrast thoracic CT:

- 150 cases are coronary CTA studies that are directly acquired, reconstructed and interpreted by the trainee. Interpretation must be mentored by an expert cardiac CT reader with level 3 training. This interpretation must be satisfactory in the judgment of the level 3 mentor.
- 150 cases are gated contrast-enhanced cardiac CT studies. These may be directly acquired and interpreted, or drawn from a case library or other teaching resource.
- 50 cases must include a noncontrast CT for calcium scoring.
- 50 cases must be coronary CTA studies with correlation to invasive angiography. These may be acquired by the trainee or read from a case library. However, for cases obtained from a library, the invasive angiography and the original CTA dataset should be reviewed (not just prepregared 3D reconstructions). The majority of the cases obtained from the library should be abnormal.

In general, level 3 requirements will be fulfilled as part of a dedicated fellowship in cardiac CT alone or in combination with other modalities (eg, magnetic resonance imaging, echocardiography, nuclear cardiology, interventional cardiology).

Level 3 competence is also accorded to currently existing practitioners of cardiac CT who were in active CT practice before January 2010, and who, by virtue of their clinical experience, research or teaching contributions to the field, are recognized as experts in cardiac CT.

Maintenance of competence

An ongoing case volume is required to ensure institutional (nurse, technologist) and physician competence in the performance of cardiac CT. Therefore, a minimum of 100 cases per reader per year is required to maintain competence. It is also essential that physicians participate in accredited CME programs to maintain their knowledge in the field.

REPORTING STANDARDS

The working group endorses the recently published guidelines for the interpretation of coronary CT by the Society of Cardiovascular Computed Tomography (3).

APPENDIX A: LEARNING OBJECTIVES

Basic computed tomography physics

1. How computed tomography (CT) works: attenuation coefficient; Beer's Law; x-ray detection system.
2. Data acquisition and image reconstruction: backprojection; filtering; slip-ring technology; spiral scanning (concept of helical pitch); spiral reconstruction.
3. Multislice CT: compared with single-slice and electron beam CT; importance of scan time; number of detectors; coverage; rotation pitch; slice thickness; volume scanning; three-dimensional (3D) reconstruction; maximum-intensity projection; multiplanar reformations (sagittal, coronal, curved); surface rendering; four-dimensional cardiac imaging.

Multislice CT imaging

1. Two-dimensional (2D) reconstruction: 2D filtered backprojection (limitations); 2D spiral reconstruction; conebeam reconstruction; coplanar projection; conebeam artifacts.
2. 3D backprojection and conebeam reconstruction: versus 2D; specific role in cardiac imaging.
3. Cardiac reconstruction: importance of immobilizing the heart; rotation speed of CT gantry; heart rate; multicycle reconstruction for better temporal resolution; physical constraints (z-axis coverage, pitch and conebeam geometry), cardiac cycles (heart rate and pitch) and angular phase (heart rate and gantry rotation speed) of segments; optimal temporal resolution and heart rate; temporal resolution and variable heart rates; optimal phase selection.
4. Gating techniques: retrospective; prospective.
5. Increasing slices per channel: effect on temporal and spatial resolutions; image acquisition time; radiation dose; slice thickness; length of breath hold.

Radiation dose in CT

1. Dose importance in CT: tube current; scan rotation time; scan length; tube voltage; trade-offs between image quality and ionizing radiation dose to the patient.
2. Dose units and measurements: absorbed dose (average energy absorbed per unit mass, mGy); effective dose (radiation risk to patient, mSv); CT dose index (CTDI) (average instantaneous dose to the patient, volume CTDI); dose length product (volume CTDI adjusted for scan length); effective dose (dose length product adjusted for region of the body).
3. Typical CT effective dose.
4. Dose efficiency (percentage of x-rays used for imaging): increase with multislice and larger detector slice thickness.
5. Dose-reduction strategies: dose modulation; automatic current adjustment.
6. Operator safety issues.

CT angiography in daily practice

1. At-home patient preparation: known/suspected contrast allergy premedication; hold phosphodiesterase inhibitors (sildenafil, vardenafil, tadalafil, etc); hold stimulants; maintain rate-control medication (beta-blockers, calcium channel blockers, etc); determine cardiac rhythm and rate (premedicate as needed); determine renal function (premedicate or postpone/cancel study as needed).
2. Workflow: pre- and post-CT preparation room monitoring; optimization of scanner use (10 min in scanner).
3. Onsite patient preparation: intravenous access (16 to 18 gauge); oral and intravenous heart rate control (if heart rate is greater than 60 beats/min); monitoring for optimal heart rate and surveillance of blood pressure.
4. Optimal contrast to noise: contrast selection, contrast dose and infusion rate on dual injection for saline chase, bolus tracking, tube current and voltage; provisions for graft patients; coverage; slice thickness and increment (pitch).
5. Optimal gating: electrode positioning; electrocardiogram (ECG) changes with position and breath hold; verify ECG tracking, heart rate, arrythmia.
6. Review before patient leaves table: adequate coronary and left ventricle filling; left ventricle brighter than right ventricle and coronary arteries brighter than veins; no excessive motion.
7. Reconstruction: ECG editing; selection of reconstruction phases; selection of filter (obese patients, stents).

CT angiography image interpretation at the console

1. Assessment of image quality; artifacts.
2. Interpretation from source axial images.
3. Strengths and caveats of maximum intensity projection, multiplanar reformation and volume-rendered images.
4. Limitations of spatial resolution; accuracy of diameter stenosis measurement in native coronary artery disease.
5. Impact of calcifications on diagnostic accuracy.
6. Diagnostic accuracy in coronary stents and bypass grafts (saphenous vein and internal mammary artery).
7. Reporting standards.

Normal cardiac anatomy and physiology

1. General orientation: cardiac chambers; valves; great vessels; coronary arteries in axial, sagittal, coronal views, and cardiac long-axis (left two-chamber, four-chamber and semi-four-chamber) and short-axis views; left ventricle inflow and outflow views; right ventricle inflow and outflow views.
2. Specific characteristics and anatomical definitions of aortic valve, left ventricle, mitral valve, left atrium, pulmonary valve, right ventricle, tricuspid valve and right atrium.
3. General orientation of epicardial coronary arteries in standard coronary angiography views: left coronary system in left anterior oblique (LAO)-cranial, right anterior oblique (RAO)-cranial, LAO-caudal and RAO-caudal views; right coronary artery in LAO, anteroposterior-cranial and RAO views.
4. Specific characteristics and anatomical definitions of epicardial coronary arteries based on the Bypass Angioplasty Revascularization Investigation (BARI) modification of the Coronary Artery Surgery Study (CASS) definitions, including coronary artery origin, trajectory and dominance.
5. Distribution of left ventricular blood supply/perfusion: which coronary artery supplies which left ventricular segment based on the American Heart Association standardized definitions.

Congenital anomalies of coronary arteries and normal variants

1. Anomalous origin from a different coronary sinus.
2. Anomalous origin from another coronary artery.
3. Anomalous origin from a great vessel.
4. Arteriovenous communications or communications between coronary artery and cardiac chamber.
5. High-risk criteria warranting intervention.
6. Myocardial bridges.
7. Clinically useful targets (what the clinician wants to know).

Pathophysiology of atherosclerosis

1. Vascular biology of atherosclerosis: pathophysiology; American Heart Association classification; stable versus unstable atherosclerosis.
2. Natural history of atherosclerosis and disease progression.
3. Disconnect between luminal diameter per cent stenosis and atherosclerosis disease burden; Glagov phenomenon.
4. Role of obstructive coronary artery disease in predicting angina symptoms but not necessarily acute coronary syndromes; role of nonhemodynamically significant coronary artery disease in acute coronary syndromes; criteria for vulnerable atherosclerosis.
5. Strengths and limitations of Hounsfield units as predictors of plaque composition.
6. Major modifiable and nonmodifiable risk factors for atherosclerosis: diabetes, dyslipidemia, hypertension, smoking, abdominal obesity, sedentary lifestyle, sex, age and family history of premature coronary artery disease.
7. Risk scores including Framingham 10-year risk of coronary event: high/intermediate/low; limitations of risk scores, predictive values and special populations including women and younger adults.
8. General basis for systemic therapy: pharmaceutical (antiplatelet, anticoagulant, lipid-lowering, angiotensin-converting enzyme inhibition, etc) and risk factor modification.
9. Special attention to the pathophysiology and significance of vessel wall calcification as a marker of atherosclerosis burden; relationship between calcification and atherosclerosis versus competing vascular disease; lack of correlation between calcium burden and luminal stenosis.
10. Calcium scoring methods including Agatston, modified Agatston, etc; strengths and weaknesses; limitations of a fixed Hounsfield unit definition of calcium and overlap.
11. Relationship between calcium scoring and other atherosclerosis risk factors.
12. Per-vessel analysis versus global calcium burden; again, the difference between calcium burden and coronary stenosis; single-vessel disease versus multivessel disease versus left main coronary artery disease.
13. Fixed cut-offs for atherosclerosis risk versus cut-offs adjusted for age and sex; reporting probability of coronary events at 10 years; integrating clinical risk scores and calcium scoring; current American Heart Association/American College of Cardiology expert consensus and European Society of Cardiology recommendations focusing on asymptomatic intermediate-risk patients.
14. Evolution of coronary artery calcification: clinically useful or useless in the assessment of disease progression/regression and therapeutic success.
15. Clinically useful targets (what the clinician wants to know).

Acute coronary artery disease

1. Definitions, diagnosis and mechanisms underlying various forms of acute coronary syndrome: ST elevation myocardial infarction; non-ST elevation myocardial infarction; unstable angina.
2. Manifestations with special attention to imaging targets of the coronary arteries and cardiac anatomy, function and perfusion.
3. Definition and diagnosis of stunned myocardium.
4. Acute and chronic complications of acute coronary syndrome.
5. General basis for local and systemic therapy: pharmaceutical (thrombolysis, etc); percutaneous (primary angioplasty, rescue angioplasty, etc); surgical (coronary bypass, etc).

6. Monitoring, drug availability, support staff and staff certification (advanced cardiac life support certification) recommended for handling patients with acute coronary syndrome.
7. Overview, recognition and treatment of potential acute complications.
8. Potential role for CT in the diagnosis and risk stratification of the acute coronary syndrome patient presenting at the emergency department.
9. Clinically useful targets (what the clinician wants to know, and with what degree of urgency).

Chronic coronary artery disease

1. Pathophysiology of myocardial perfusion, including O_2 supply and demand.
2. Definition of hemodynamically significant coronary artery stenosis.
3. Difference between anatomical and physiological definition of coronary artery stenosis. A basic understanding of competing anatomical methods: quantitative coronary angiography; intravascular ultrasound; virtual histology; coronary angioscopy; magnetic resonance coronary angiography; coronary optical coherence tomography; coronary artery palpography; intravascular magnetic resonance imaging.
4. A basic understanding of competing physiological methods: difference between function and perfusion reserve; difference between exercise and pharmacological stress; nuclear single-photon emission CT imaging; nuclear positron emission tomography imaging; echocardiography including contrast echocardiography and 3D echocardiography.
5. Impact of pretest probability on accuracy (sensitivity, specificity, positive predictive value, negative predictive value); prevalence of disease; Bayes' theorem; American Heart Asssociation criteria for typical angina versus atypical angina versus noncoronary chest pain; difference between diagnosis of atherosclerosis and diagnosis of obstructive coronary artery disease.
6. Definition and pathophysiology of myocardial viability; survival benefits in revascularizing a patient with viable versus nonviable myocardium; selective revascularization of viable myocardial segments.
7. Potential role for CT in the diagnosis and risk stratification of the chronic coronary patient; potential role in planning coronary intervention in chronic total occlusion, left main coronary angioplasty, bifurcation lesion angioplasty and left main coronary artery angioplasty.
8. Competing methods in the catheterization laboratory: intravascular ultrasound; virtual histology; fractional flow reserve.
9. Strengths and limitations of CT in patients with coronary artery stents.
10. Strengths and limitations of CT in patients with coronary bypass: saphenous vein grafts; internal mammary artery grafts.
11. Clinically useful targets (what the clinician wants to know).

Nonatherosclerotic coronary artery disease

1. Pathophysiology, diagnosis and natural history of Kawasaki disease.
2. Pathophysiology, diagnosis and natural history of spontaneous coronary artery dissection.
3. Clinically useful targets (what the clinician wants to know).

Nonischemic cardiomyopathy

1. Pathophysiology and diagnostic criteria for dilated cardiomyopathy, hypertrophic cardiomyopathy, restrictive cardiomyopathy (focus on amyloidosis, sarcoidosis and hemochromatosis), diabetic cardiomyopathy, arrythmogenic right ventricular dysplasia and ventricular noncompaction.
2. Pathophysiology and diagnostic criteria for myocarditis.
3. Pathophysiology and diagnostic criteria for constrictive pericarditis: acute inflammatory; chronic fibrous; effusive-constrictive; adhesive.
4. Definitions of ventricular function: right versus left; systolic versus diastolic; global versus segmental. Methods: volumetric versus nonvolumetric (geometric assumptions); impact of loading conditions (preload, afterload); impact of including versus excluding papillary muscles from ventricular blood pool. Basic knowledge of competing methods: echocardiography; contrast ventriculography; isotopic ventriculography; magnetic resonance imaging.
5. Clinically useful targets (what the clinician wants to know).

Valvular heart disease

1. Definitions and pathophysiology of valvular stenosis and regurgitation; definitions of disease severity; integration with cardiac chamber assessment and clinical markers of severity.
2. Assessment of leaflet number, morphology and function.
3. Planimetry of valvular orifice area: limitations of anatomical orifice area versus effective (physiological) orifice area.
4. Assessment of valvular prosthesis: leaflet mobility.
5. Clinically useful targets (what the clinician wants to know).

Congenital heart disease

1. Basic understanding of cardiac embryology and development.
2. Review of situs abnormalities, and abnormalities of ventricular morphology and position.
3. Assessment for intracardiac and extracardiac shunts.
4. Assessment of extracoronary cardiac normal variants (ventricular diverticuli, accessory left atrial appendage, etc).

Great vessels and venous circulation

1. Definitions and pathophysiology of aortic dissection and aortic aneurysm; monitoring, drug availability, support staff and staff certification (advanced cardiac life support certification) recommended for handling patients with aortic dissection; potential acute complications in patients with aortic dissection.
2. Definitions and pathophysiology of pulmonary vein stenosis.

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