2020 SCCT Guideline for Training Cardiology and Radiology Trainees as Independent Practitioners (Level II) and Advanced Practitioners (Level III) in Cardiovascular Computed Tomography: A Statement from the Society of Cardiovascular Computed Tomography

Andrew D. Choi, MD* • Dustin M. Thomas, MD* • James Lee, MD • Suhny Abbara, MD • Ricardo C. Cury, MD • Jonathon A. Leipsic, MD • Christopher Maroules, MD • Prashant Nagpal, MD • Michael L. Steigner, MD • Dee Dee Wang, MD • Michelle C. Williams, MBChB, PhD • Irfan Zeb, MD • Todd C. Villines, MD* • Ron Blankstein, MD*

From the Division of Cardiology & Department of Radiology, The George Washington University School of Medicine, 2150 Pennsylvania Ave NW, Suite 4-417, Washington, DC 20037 (A.D.C.); Heart Institute, Parkview Health, Fort Wayne, Ind (D.M.T.); Department of Medicine, Division of Cardiology, Henry Ford Health System, Center for Structural Heart Disease, Detroit, Mich (J.L., D.D.W.); Division of Cardiothoracic Imaging, Department of Radiology, University of Texas Southwestern Medical Center, Dallas, Tex (S.A.); Miami Cardiac and Vascular Institute, Baptist Health of South Florida, Miami, FL, United States and Department of Radiology, Herbert Wertheim College of Medicine, Florida International University, Miami, FL (R.C.C.); Department of Radiology, St. Paul's Hospital, Vancouver, Canada (J.A.L.); Department of Radiology, Naval Medical Center, Portsmouth, Va (C.M.); Department of Radiology, University of Iowa Hospitals and Clinics, Iowa City, Iowa (P.N.); Cardiovascular Imaging Program, Department of Radiology, Brigham and Women's Hospital, Boston, MA, United States (M.L.S.); University of Edinburgh/British Heart Foundation Centre for Cardiovascular Science, Edinburgh, United Kingdom (M.C.W.); Division of Cardiology, West Virginia University School of Medicine, Morgantown, WV (I.Z.); and Division of Cardiology, University of Virginia Health System, Charlottesville, Va (T.C.V.); Cardiovascular Imaging Program, Departments of Medicine (Cardiovascular Division) and Radiology, Brigham and Women's Hospital, Boston, MA, United States (R.B.). **Address correspondence to** A.D.C. (e-mail: *adchoi@mfa.gwu.edu*).

*Guideline Co-Chairs

Conflicts of interest are listed at the end of this article.

Cardiovascular computed tomography (CCT) is a well-validated noninvasive imaging tool with an ever-expanding array of applications beyond the assessment of coronary artery disease. These include the evaluation of structural heart diseases, congenital heart diseases, peri-procedural electrophysiology applications, and the functional evaluation of ischemia. This breadth requires a robust and diverse training curriculum to ensure graduates of CCT training programs meet minimum competency standards for independent CCT interpretation. This statement from the Society of Cardiovascular Computed Tomography aims to supplement existing societal training guidelines by providing a curriculum and competency framework to inform the development of a comprehensive, integrated training experience for cardiology and radiology trainees in CCT.

This article is being published synchronously in *Radiology: Cardiothoracic Imaging, Journal of Cardiovascular Computed Tomography*, and *JACC: Cardiovascular Imaging*.

© 2020 Society of Cardiovascular Computed Tomography. Published by RSNA with permission.

Background and Scope

The field of cardiovascular computed tomography (CCT) has seen considerable growth over the past decade. Driven in large part by a growing body of evidence and significant advancements in scanner technology, societal guidelines internationally now strongly recommend CCT, as the preferred first-line test in patients without known coronary artery disease (1–3). The recently updated National Institute for Health and Care Excellence (NICE) guidelines in the United Kingdom (UK) recommend CCT as the preferred testing strategy for stable chest pain patients without known CAD, citing accuracy of diagnosis, as well as economic and prognostic advantages (4,5). One challenge facing this increased utilization of CCT in the UK is the need for more independent CCT practitioners and/or advanced practitioners capable of leading a CCT laboratory (6). In the US, data from recent clinical trials, and an increased emphasis on value based care are contributing to a similar shift toward increased utilization of CCT, and thus a similar need for a higher number of independent CCT readers

(7–9). This is expected to drive a similar need for more independent and advanced CCT practitioners.

In addition to the evaluation of CAD, the role for CCT in the evaluation of structural cardiac disease continues to expand rapidly, is now a prerequisite imaging study for the optimal planning of transcatheter, surgical and congenital therapies, and is expected to further evolve in the future (10,11). The modern cardiology and radiology trainee pursuing CCT training should be comfortable with the scope and fundamentals of these various non-coronary applications. In the United States, societal training guidelines from the American College of Cardiology (ACC) and American College of Radiology (ACR) inform the case volume and clinical skills that are required to become accredited as an independent reader or as a laboratory director (12,13).

Internationally, several training statements incorporate CCT training. The 2014 Royal College of Radiologists/ British Society of Cardiovascular Imaging document addresses the safe practice of CT coronary angiography (14). The European Association of Cardiovascular Imaging

developed a CCT Core Syllabus in 2015 that gives a broad overview to educational topics that constitute competency for CCT practice (15). Recently, the Royal College of Radiology Clinical Radiology Specialty Training Curriculum 2020 has incorporated CCT training (16). The Society of Cardiovascular Computed Tomography (SCCT) published a statement in 2015 outlining a comprehensive curriculum for cardiology and radiology program directors to design an educational experience in the basic, foundational (level I) aspects of CCT (17). To complement these statements, there is a need to assist program directors in designing a comprehensive academic curriculum to address advanced level trainees capable of performing and interpreting complex studies, lead a research program, direct a CCT laboratory and/or train others in CCT.

This document strives to provide guidance for program directors (PD) charged with designing a curriculum for the training of **Independent Practitioner (IP; Level II)** and/or **Advanced Practitioner (AP; Level III)** (Table 1). In the U.S., the Accreditation Council for Graduate Medical Education (ACGME) adopted a set of 6 core competencies that make up the cornerstone trainee education and assessment: 1) medical knowledge; 2) practice-based learning and improvement (PBLI); 3) patient care and procedural skills; 4) systems-based practice; 5) interpersonal and communication skills; and 6) professionalism.

Furthermore, this document uses the framework of the ACGME core competencies as a global document to enable the assessment and education of trainees across these core competencies to reproducibly train graduating fellows and residents fully qualified to care for patients utilizing CCT. Thus, this document aims to reinforce learning competencies utilized regularly in clinical practice through daily case volume. It also aims to provide a guide for necessary medical knowledge and online case volume supplementation needed to expose the trainee to less frequently encountered CCT applications.

CCT trainees emerge from two principle training backgrounds: radiology or cardiology. Importantly, it is not so much what specialty a prospective CCT reader originates from, but rather the quality of dedicated training that they obtain that ultimately defines competency level and expertise in the advanced field of CCT. Indeed, the strong collaboration between radiologists and cardiologists-in clinical practice, research, and in training-has fueled many of the advances in the field of CCT (18). The challenge for radiology and cardiology PDs is to identify training gaps in their respective curriculum and augment the training experience to incorporate all necessary learning objectives, regardless of local expertise, case diversity, or case volume.

Additionally, consideration should be given to tailoring a training curriculum based specifically on augmenting known knowledge gaps. Cardiology fellows, as an example, may require a

Table 1: Summary of Independent Practitioner (IP) and Advanced Practitioner (AP) Capabilities upon Completion of Training

Final Training Level	Definition
Independent Practitioner (IP)	• Achieved competency to independently interpret cardiac findings on noncontrast and predominantly contrast-enhanced cardiac CT • Achieved competency to independently evaluate patient selection, preparation, scan protocol selection, dose modulation, postprocessing, and image interpretation • Achieved competency in all of the common cardiac CT applications to include evaluation of coronary pathology, coronary anatomy, basic structural HD assessment, EP procedural planning, basic congenital HD, and functional CT
Advanced Practitioner (AP)	• Achieved competency in all capabilities ascribed to IP level of training • Achieved advanced skills and knowledge beyond IP, including evaluation of complex coronary artery disease, competency in structural heart planning and a wider spectrum of congenital heart disease • Achieved competency in vascular CT • Achieved competency in laboratory accreditation requirements and maintenance • Achieved competency in equipment purchasing, maintenance, and acquisition • Actively involved in quality improvement, performance improvement, and/or CT-specific research endeavors • Achieved competency in business aspects (billing, coverage, reimbursement, and prior authorization) of CT laboratory administration

training curriculum weighted more heavily in CT physics, protocol optimization, and extra-cardiac anatomy, and pathology. Conversely, radiology residents may benefit from a training curriculum focused more on cardiac anatomy, clinical outcomes data, clinical practice guidelines, management of cardiovascular disease, and cardiac pathophysiology. Figure 1 outlines potential CCT training pathways for both cardiology fellows and radiology residents. Given local variations in case volume, diversity, and supervisor expertise, training duration for IP/Level II trainees may vary.

Current Requirements for Radiology Trainees

Less variability typically exists with respect to IP training for radiology residents. General curriculum requirements are completed during the first 3 years of training and IP requirements are accomplished during focused cardiac imaging training, typically during the fourth year of training. For radiology and nuclear medicine residents, the American College of Radiology (ACR) released an update to CT accreditation program requirements in July 2015 (19). The ACR statement lays out minimum initial requirements with respect to CCT case volume, board certification and/or training, and additional education in cardiac structure and function in order to interpret and supervise CCT examinations.

More recently in 2016, a joint practice parameter collaboratively revised by ACR in concert with the North American Society of Cardiovascular Imaging (NASCI) and the
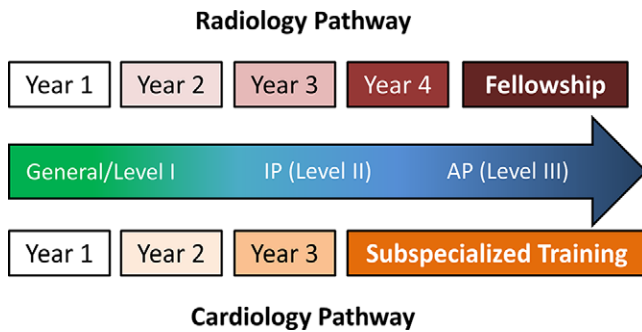
Radiology Pathway

Figure 1: **Recommended Pathways to Independent Practitioner & Advanced Practitioner from Cardiology or Radiology Training Backgrounds** Local variations in case volume, diversity, and supervisor expertise may allow for completion of IP case volume and requirements as early as the second year of cardiology fellowship. Less variability typically exists with respect to IP training for radiology residents. General curriculum requirements are completed during the first 3 years of training and IP requirements are accomplished during focused cardiac imaging training, typically during the fourth year of training. AP training requires additional fellowship training in advanced cardiac imaging.

Society of Pediatric Radiology (SPR) was published that differs slightly from the 2015 ACR statement (13). The joint 2016 practice parameter lowered the number of dedicated cardiac CT examinations performed to 50 studies over a 36 month period (compared with 75 in the 2015 ACR CT accreditation requirements statement) while also lowering the required continuing medical education (CME) hours to 30 (from 40 hours); while maintaining board certification and training program accreditation standards established in the 2015 ACR statement. Importantly, the 2016 joint practice parameter also outlined qualifications required to assume responsibility of a cardiac CT imaging program or laboratory. In addition to the previously discussed requirements, an additional 450 supervised thoracic CT or CT angiography cases, excluding CAC scoring, are required and an additional 200 hours of CT-specific CME.

Nuclear medicine training is much more variable as trainees can emerge from both internal medicine and radiology. Thus, these trainees should follow guidance found in the ACR statement (19). In brief, radiology trainees are required to successfully complete board certification through a recognized governing body (ie, American Board of Radiology, Royal College of Physicians and Surgeons of Canada, etc). Importantly, no distinction is made between IP and AP levels of competency.

Current Requirements for Cardiology Trainees

Independent Practitioner (Level II).—Cardiology fellows training at high volume centers may complete IP case volume requirements within a shorter period of time when compared with cardiology fellows at lower volume centers. CCT training may be incorporated into multimodality imaging rotations to complete IP requirements. Adding to the variability is the fact that general cardiology fellowship training can vary in duration (as short as 24 months of clinical rotations up to 36 months), thus potentially shortening the time available to train IP-level trainees (20). While the 2015 ACR statement men-

tions training recommendations for IPs originating from a cardiology background, training requirements for various levels of competency for cardiology fellows are governed by the Core Cardiovascular Training Statement (COCATS) published by the American College of Cardiology (12). COCATS 4 provides a case-volume recommendations, in addition to general ACGME core competency-based training objectives ("milestones") for both Level I and Level II general cardiology fellows (12). Training requirements highlighted in COCATS 4 call for significant hands-on time spent with contrast-enhanced CCT dataset acquisition and patient preparation with a focus on mentored case review at a 3-dimensional (3D) workstation. In general, level I concepts should be met within the first 2 years of fellowship training with more focused case exposure and didactic training required in the 3 year of training to achieve Level II competency during a standard general cardiology fellowship.

Advanced Practitioner (Level III).—AP learners requires additional training in hybrid imaging modalities, participation in the various aspects of laboratory administration, education of cardiology and/or radiology trainees, and participation in CCT-specific research. In addition to devoted training in CCT, an AP trainee is required to achieve advanced training in at least 1 additional imaging modality. Given these extensive requirements, COCATS recommends additional training beyond the standard 3-year fellowship, though this is not explicitly required. In the U.S. multiple cardiovascular imaging fellowships are available that enable trainees to acquired advanced knowledge and skills that enable trainees to achieve level II or level III in multiple imaging modalities. Around the world CCT is an important component of standard cardiology curriculum. For example in the UK, the Joint Royal Colleges of Physicians Training Board incorporates CCT in its specialty training curriculum for cardiology trainees (21). In addition, the length of cardiology training varies widely, and additional training in CCT may be required to achieve AP level.

Statement of Purpose

Taking this background into account, the purpose of this statement is threefold. First, we seek to expand upon the SCCT general (Level I) curriculum guideline statement by providing knowledge and skills required for IP and AP trainees. Second, we seek to provide enhanced granularity and standardization across advanced imaging fellowship curricula and across a broad range of training backgrounds (radiology and cardiology). Finally, we seek to fill in identified gaps in currently published training recommendation statements and emphasize that background knowledge and procedural skill are important requirements delineated in the COCATS and ACR statements. Specifically, this document delineates a suggested minimum threshold for AP case volumes to achieve the milestones outlined. This guideline is not meant to supersede the existing COCATS and ACR statements, but rather complement those documents to encompass the most recent advancements in the field of CCT.

Table 2: ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	Training Level								
	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
Radiation/Radiation Safety									
Understand and effect minimizing acquisition field of view to reduce radiation exposure	X	X		X					
Understand the concept of exposure control techniques for tube current modulation	X	X		X					
Understand how ECG gating protocols effect radiation exposure	X	X		X					
Understand and explain stochastic and deterministic effects of radiation exposure as it relates to CCTA	X	X		X	X	X	X	X	
Recognize clinical indication-based patient specific scan protocol modifications to reduce radiation exposure without sacrificing image quality	X	X		X		X		X	
Understand effect of pitch and slice increment on CT dose index	X	X	*	X					
Understand benefits and limitations of radiation effective dose estimations	X	X	*	X					
Understand how iterative reconstruction versus filtered back projection affects image noise and may enable reduction in radiation exposure	X	X	*	X					
Active quality improvement in radiation dose management		X	*			X	X	X	X
CT Fundamentals									
Derive local standards and criteria for appropriate education and dissemination of CCTA fundamentals for medical staff, technologists and trainees	X	X	*	X	X		X		X
Understand the impact of the attenuation coefficient of various tissues	X	X	*	X					
Understand the generation of the image matrix and individual voxels and summarize difference between acquisition field of view and reconstruction field of view as it relates spatial resolution	X	X	*	X					
Summarize the various dual energy CT (DECT) acquisition techniques (eg, dual source, sequential, dual layer, rapid kV switching) and their potential applications		X	*	X					
Patient Selection, Preparation, and Management									
Demonstrate competency discussing risks and benefits of CCT with patients and referring clinicians	X	X			X				
Understand, explain, prevent and treat potential adverse reactions for iodinated contrast (ie, IV infiltration, rash, anaphylaxis, renal dysfunction)	X	X		X	X	X	X	X	X
Manage complications related to other CCT medications (eg, hypotension after sublingual nitroglycerin, unstable bradycardia/heart block after beta-blockers)	X	X		X		X			
Understand risks and contraindications of CCTA for pregnant patients	X	X		X	X	X	X		
Understand patient preparation for use of CCT for pulmonary vein and left atrial appendage identification	X	X	*	X		X			
Understand the evidence on the use of CCT for diagnosis and risk stratification of coronary artery disease in women	X	X	*	X	X	X	X	X	X
Image Acquisition and Protocols									
Demonstrate mastery of ECG triggering/gating strategies	X	X		X		X			
Understand IV contrast bolus geometry, timing techniques and protocols, and optimize for cardiac chamber of interest	X	X		X		X			
Appropriate triage of high risk and unstable patients with acute coronary syndrome, acute aortic syndromes, or pulmonary embolus	X	X		X	X	X	X		
Recognize challenging scanning conditions and implement strategies for optimizing image quality	X	X		X		X	X	X	X
Minimize unnecessary or inappropriate CCT imaging, to include cancelling CCT studies when patient parameters are unfavorable despite appropriate preparation	X	X			X	X	X	X	X

Table 2 (*continues*)

Note.—AP = advanced practitioner, IP = independent practitioner, New = new curriculum, MK = medical knowledge, ICS = interpersonal & communication skills, PC = patient care, SBP = systems-based practice, P = professionalism, PLI = practice-based learning & improvement.
* Denotes in the "New" column annotated learning objectives that are new to this document and not previously recommended in SCCT Level I Curriculum (17), COCATS 4 (12) or by the ACR (19).

Table 2 (continued): ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	Training Level								
	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
Understand multi-cycle reconstruction techniques and the effect on temporal resolution	X	X	*	X					
Understand protocol for stress and rest myocardial CT perfusion studies		X	*	X	X				
Reconstruction, Post-processing and Artifacts									
Describe multiple patient preparation, protocol selection, and reconstruction/postprocessing steps that can be used to minimize patient and cardiac motion	X	X		X					
Describe scanner-based and preparation-based techniques to minimize physics-based, patient-based, and scanner-based artifacts	X	X		X					
Optimize image quality by performing ECG editing when needed	X	X		X		X			X
Demonstrate the ability to use convolution kernels and postprocessing filters	X	X	*	X					
Demonstrate the ability to create 3D volume renderings for visualization of complex anatomy	X	X	*	X					
Understand the emerging role of advanced postprocessing tools in CCT including machine learning, radiomics, atherosclerosis plaque quantification, coronary perivascular fat attenuation and 3D printing		X	*	X		X			
Coronary Anatomy and Pathology									
Identify coronary artery atherosclerotic disease burden	X	X			X	X			
Estimate coronary stenosis severity using the CAD-RADS scoring system, as well as include applicable modifiers when pertinent to standardize reporting practice	X	X	*	X				X	X
Recognize plaque features which are associated with increased risk (ie, plaque vulnerability) such as positive remodeling, low attenuation plaques, spotty calcification and napkin ring sign	X	X		X					
Identify myocardial coronary bridging, characterize pertinent imaging and clinical features including benign prognosis	X	X	*	X					
Identify coronary artery dissections, aneurysm, fistulae, and anomalous origins	X	X		X					
Assess coronary artery bypass graft for patency and stenosis	X	X		X					
Evaluate patency of coronary stents, recognize in-stent restenosis	X	X		X					
Summarize and identify coronary manifestations in connective tissue disorders, vasculitis, and fibromuscular dysplasia.		X	*	X					
Coronary Calcium									
Demonstrate how CAC testing can be used in primary prevention, including indications for use, guideline-centered risk-stratification and shared decision-making for preventive pharmacotherapy interventions	X	X	*	X					
Understand how CAC testing is performed and quantitated by a gated Agatston method as well as from nongated CT studies	X	X	*	X					
Understand how CAC testing can accurately and effectively communicate individual patient risk based on validated population-based scoring systems	X	X	*		X	X			
Understand application of radiation dose reduction techniques in CAC testing	X	X	*	X	X				
Demonstrate the use of a standardized method to communicate findings of CAC scanning on gated and nongated studies to facilitate clinical decision making using the Coronary Artery Calcium Data and reporting System (CAC-DRS)	X	X	*	X	X	X	X	X	X
Non-coronary Cardiac									
Recognize cardiomyopathies including hypertrophic cardiomyopathy, arrhythmogenic RV cardiomyopathy (ARVC), dilated cardiomyopathy, infiltrative cardiomyopathy, and LV noncompaction	X	X	*	X		X			

Table 2 (continues)

Table 2 (continued): ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	Training Level								
	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
Incorporate multisociety guidelines into local laboratory standards for use of CCT in the evaluation of EP procedure planning (eg, catheter ablation)	X	X	*	X	X	X		X	
Understand use of CCTA for valvular heart disease including native, bioprosthetic and mechanical valves	X	X		X		X			
Recognize valvular infective endocarditis and common associated complications	X	X		X		X			
Incorporate multimodality imaging with CCT findings in the setting of significant noncoronary cardiac pathology		X	*				X		
Identify advanced pericardial diseases and pericardial complications of implantable cardiac devices	X	X	*	X		X			
Incorporate and appropriately protocol CCT for coronary vein mapping prior to implantation of a cardiac resynchronization device		X		X		X			
Non-cardiac									
Recognize common incidental thoracic and upper abdominal findings encountered in CCT	X	X		X		X			
Demonstrate proficiency in recognizing incidental findings that require follow-up (eg, pulmonary nodules via recent Fleischner Society Criteria) or immediate treatment (eg, pulmonary embolus) and coordinate appropriate follow-up imaging or consultation	X	X		X	X	X	X	X	X
Participates in local quality initiatives for evaluation of incidental noncardiac findings, including follow-up evaluation of pulmonary nodules		X	*				X		X
Leadership and Laboratory Accreditation									
Establish a culture of effective and professional communication with members of the health care team, including CT technologists and nursing staff	X	X	*		X	X	X	X	X
Demonstrates the following professional behaviors: • Recognizes the importance and priority of patient care and advocates for patient interests • Recognizes personal limitations and seeks help when appropriate • Exhibits tolerance and acceptance of diverse individuals and groups • Maintains patient confidentiality	X	X	*		X	X	X	X	X
Training under the supervision of a medical director with independent reader/level certification at a minimum and at least 1 faculty member with board certification in cardiac CT who are actively fulfilling recommended minimum case volumes for ongoing certification	X		*	X	X	X	X	X	X
Training should be in an environment with a medical physicist (or equivalent individual) that can provide education on radiation safety and protocol optimization	X	X	*	X	X	X	X	X	X
Communicate complex and difficult information, such as errors, complications, and adverse events	X	X	*		X	X	X	X	X
Understand pregnancy screening policy	X	X	*			X	X		
Understand appropriate renal precautions and study protocolization in patients with normal and impaired kidney function including minimizing contrast while achieving diagnostic imaging	X	X	*			X	X		
Ensure nursing and staff have appropriate training in administration of drugs commonly used in CCT and understand the indications and contraindications	X	X	*	X	X	X	X		

Table 2 (continues)

Table 2 (continued): ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	Training Level								
	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
Training under the supervision of a medical director with advanced practitioner/level III certification at a minimum and at least 1 faculty member with board certification in cardiac CT who are actively fulfilling recommended minimum case volumes for ongoing certification	X	X	*	X	X	X	X	X	X
Medical director should work closely with trainee on laboratory management and participation in accreditation by appropriate certifying body	X	X	*		X		X	X	X
Review and ensure standardized and timely reporting practices	X	X	*				X		X
Active, regular development of quality improvement initiatives	X	X	*				X		X
Understanding of the appropriate billing/CPT codes for CCT	X	X	*				X		
Vascular CT									
Understand appropriate patient selection for peripheral CT angiography & venography		X		X		X			
Describe common aortic arch and upper extremity vascular variants	X	X	*	X					
Recognize and identify acute aortic syndromes (rupture, aneurysm, aortic dissection, intramural hematoma, penetrating ulcer)	X	X		X		X			
Understand appropriate thoracic aortic aneurysm measurements, management and follow-up	X	X		X		X			
Understand selection of ECG-gated versus non-gated acquisitions for vascular CTA	X	X	*	X					
Describe normal and variant renal, mesenteric, pelvic, and lower extremity arterial anatomy and be able to recognize clinically significant disease		X	*	X		X			
Describe normal and variant renal, mesenteric, pelvic venous anatomy and vasculature including compression syndromes (ie, May-Thurner, nutcracker syndrome)		X	*	X		X			
Identify abnormal thoracic and abdominal venous (ie, persistent left subclavian vein, azygous continuation of inferior vena cava)		X	*	X		X			
Recognize vascular inflammatory syndromes (ie, Takayasu's arteritis)		X	*	X		X			
Structural Heart Disease									
Proficiency in protocoling and interpretation of retrospective-ECG gated imaging for identification of prosthetic valve dysfunction	X	X	*	X		X			
Identify optimal fluoroscopic projections in structural heart disease procedural planning	X	X	*						
TAVR: Understand indications of CCTA for pre-procedure planning of TAVR including valve sizing and vascular access planning	X	X	*	X		X			
TAVR: Assess aortic valve calcium quantification by CCT to assist in determination of degree of valvular stenosis	X	X	*	X		X			
TAVR: Reproducibly measure aortic annulus in the appropriate phase of the cardiac cycle to aid in TAVR device sizing and selection	X	X	*	X		X			
TAVR: Describe how secondary measurements and landing zone calcium of the aorto-annular complex impact CT prediction of procedural risk including paravalvular leak or ventricular septal defect from infra-annular calcium or coronary obstruction by the aorto-annular complex	X	X	*	X		X			
TAVR: Use CCT in planning of TAVR valve-in-valve procedures for sizing and prediction of risk	X	X	*	X		X			
TAVR: Understand the evolving role of CCT for post TAVR imaging (ie, hypoattenuated leaflet thickening [HALT] and hypoattenuation affecting motion [HAM])	X	X	*	X		X			
TAVR: Assess femoral vasculature for adequate size for TAVR delivery catheters	X	X	*	X		X			

Table 2 (continues)

Table 2 (continued): ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
TAVR: Assess peripheral vasculature for alternative vascular access sites if inadequate femoral vasculature	X	X	*	X		X			
TAVR: Assess for carotid protection device feasibility		X							
TAVR: Participate in the multidisciplinary "Heart Team" utilizing CCT	X	X	*		X		X	X	X
TMVR: Understand the spectrum of prosthetic mitral valves and rings and their impact on feasibility for TMVR	X	X	*	X		X			
TMVR: Predict risk of left ventricular outflow tract obstruction after deployment of TMVR (neo-LVOT)		X	*	X		X			
TMVR: Identify adequate landing zone assessment (ie, annulus, mitral annular calcium, prosthetic valve or mitral valve-in-ring)		X	*	X		X			
TMVR: Assess site of optimal trans-septal or transapical puncture site		X	*						
LAA Occlusion: Understand protocol and ability to evaluate for left atrial appendage thrombus	X	X	*	X		X			
LAA Occlusion: Sizing of left atrial appendage for occlusion device and prediction of C-arm deployment angles		X	*	X		X			
VAD: Understand appropriate use of CCT in the evaluation of left ventricular assist devices (VAD)	X	X	*	X		X			
VAD: Understand how CCTA can assist in evaluating VAD function and complications including malpositioning, pump thrombosis, outflow graft kinking and hemorrhage	X	X	*	X		X			
Paravalvular leak: Identify location, shape and size to determine potential barriers for device deployment	X	X	*	X		X			
ASD/PFO Closure: Assess size and evaluation of margins for device deployment	X	X	*	X		X			
Congenital Heart Disease (CHD)									
Understand and perform patient specific IV contrast injection protocols for CHD patients	X	X	*	X			X		
Demonstrate knowledge of pediatric and adult doses for heart rate lowering medications, sublingual nitroglycerin and contraindications to these medications	X	X	*	X			X		
Demonstrate the ability to communicate complex anatomic details to surgeons/interventionists for identification of abnormalities and planning corrective procedures	X	X	*	X	X	X	X		
Understand the basic anatomy of native and repaired simple CHD (ie, BAV, ASD/VSD, TOF)	X	X	*	X		X	X		
Recognize spectrum of congenital valve pathologies	X	X	*	X		X			
Understand the basic anatomy of native (ie, Transposition of the Great Arteries (TGA), Tricuspid Atresia (TA), single ventricle) and repaired complex CHD (ie, Atrial switch Rastelli, Nikaidoh, Glenn, Fontan, Ross procedures)	X	X	*	X		X	X		
Recognize variants of anomalous coronary artery origins, courses, aneurysms, and fistulas	X	X	*	X		X			
Recognize congenital abnormalities of pulmonary and systemic venous drainage	X	X	*	X		X			
Demonstrate the ability to recognize pathologic vascular rings and spatial relationship of aorta and pulmonary arteries to the trachea and esophagus	X	X	*	X		X			
Understand the unique challenges in the pediatric population including the use of sedation and optimal heart rate control for better image quality and radiation reduction techniques	X	X	*	X			X		

Table 2 (continues)

Table 2 (continued): ACGME Core Competency-Based Cardiac CT Training Curriculum Knowledge Bullet Points

	IP (Level 2)	AP (Level 3)	New	MK	ICS	PC	SBP	P	PLI
				Training Level					
Apply CHD knowledge in the planning of catheter or surgical procedures for palliation or repair of CHD		X	*	X		x			
Understand the role of CCT in neonate or young patients with complex anatomy, particularly if at higher risk for an adverse event with sedation or anesthesia required for CMR		X	*	X		x			
Functional Testing for Coronary Artery Disease									
Understand the comparative effectiveness of CCT versus stress testing for guiding patient management	X	X	*	X		X	X		
Recognize CCT findings which may impact coronary revascularization decisions (eg, high risk anatomy)	X	X	*	X			X		
Describe the basic principles, strengths, limitations, and clinical trial data supporting stress CT-Perfusion (CTP)	X	X	*	X					
Describe the basic principles, strengths, limitations, and clinical trial data for Fractional Flow Reserve (FFR-CT) methods	X	X	*	X					
Recognize prior myocardial infarction and understand how to adjust scan data including window width and level to evaluate for resting perfusion abnormalities	X	X	*	X					
Understand the technical protocol, requirements and application of static and dynamic CTP for functional assessment of coronary artery disease		X	*	X		X	X		
Understand the technical protocol, requirements and application FFR-CT for functional assessment of coronary artery disease		X	*	X		X	X		
Recognize strengths/limitations of other novel CCT methods for ischemia/infarction evaluation such as late contrast enhancement		X	*	X					

Note.—AP = advanced practitioner, IP = independent practitioner, New = new curriculum, MK = medical knowledge, ICS = interpersonal & communication skills, PC = patient care, SBP = systems-based practice, P = professionalism, PLI = practice-based learning & improvement.

ECG = Electrocardiogram; 3D = 3-Dimensional; CAD-RADS = Coronary Artery Disease-Reporting and Data System; CAC = Coronary artery calcium; TAVR = Transcatheter Aortic Valve Replacement; TMVR = Transcatheter Mitral Valve Repair; LAA = Left Atrial Appendage; VAD = Ventricular Assist Device. CHD = Congenital Heart Disease. BAV = Bicuspid aortic valve; ASD = Atrial Septal Defect; PFO = Patent Foramen Ovale; VSD = Ventricular Septal Defect; TOF = Tetralogy of Fallot; TGA = Transposition of the Great Arteries; TA = Tricuspid Atresia; CMR = Cardiovascular Magnetic Resonance. CTP = Computed Tomography Perfusion. FFR = Fractional Flow Reserve.
* Denotes in the "New" column annotated learning objectives that are new to this document and not previously recommended in SCCT Level I Curriculum (17), COCATS 4 (12) or by the ACR (19). CCT = cardiac computed tomography; IP = Independent Practitioner; AP = Advanced Practitioner.

Training Components

Identification of General Training Gaps

As this document builds upon the curriculum previously outlined in the 2015 SCCT Level I curriculum guideline (17), a comprehensive training curriculum with a goal of producing competent IP and AP imagers should be tailored to the specific strengths and limitations of training background (cardiology, radiology, or nuclear medicine), total laboratory case volume, and case diversity. Building an initial curriculum or revamping an existing curriculum for IP and AP trainees is a complex undertaking. Radiology residents/trainees may have a stronger foundation in CT scanner strengths, limitations, protocol selection, postprocessing, and image manipulation. Cardiology fellows/trainees may have a deeper understanding of cardiac anatomy, physiology, pathologic disease states, and the clinical applicability of these various findings, but minimal exposure to CT as an imaging modality. A team-based approach to the hands-on scanner training experience, which could involve technologist, medical physics, and the laboratory director, could also increase the level of understanding and depth of knowledge. In addition, AP trainees may require exposure to multiple scanner platforms and to a diverse case volume that should involve multidisciplinary image interpretation and clinical correlation of findings.

Understanding that a critical review and potential revision of a CCT training curriculum can be time consuming, this document seeks to ease this transition in several ways. First, recommended learning objectives are found in Table 2 and are arranged by ACGME core competency and further broken down by core CCT domain for both IP and AP trainees. The ACGME core competencies were used to allow for PDs to more easily develop trainee evaluations to ensure learners are meeting

specific milestones and to identify knowledge gaps earlier in training where they can more easily be addressed.

Case Volume and Case Diversity

Case volume and diversity are important aspects for potential IP & AP trainees, as there is data linking increasing case volumes with successful completion of board certification examinations (22). Of greater importance, the case volumes discussed within this document serve as a starting point for competency that must be assessed and verified by CCT advanced practitioners. This can be learned and evaluated during live case manipulation at a dedicated 3D workstation. It is important that IP & AP trainees be directly mentored by a supervising faculty with routine involvement in image acquisition and protocol selection at the scanner. In many institutions, though, there is limited case volume and diversity that is reliably available for all trainees and thus alternative training resources are needed. Supplementation with electronic teaching files and/or online resources with emphasis on maximal exposure to 3D workstation functionality may assist with bridging this gap.

Integration and leveraging of expertise from cardiology and radiology resources within a training center can significantly augment an IP and AP training curriculum (18). PDs are strongly encouraged to coordinate with these other departments to arrange for multidisciplinary conferences, multimodality imaging correlations, and joint live interpretation at the 3D workstation. With regard to minimum case volumes for IP and AP competency (Tables 3–5), the writing group arrived at these recommendations through unanimous consensus.

Structural Heart Disease (SHD)

The widespread adoption of transcatheter aortic valve replacement (TAVR) has driven a strong interest in the field of structural heart disease. During the development of TAVR, CCT has become integral to the preprocedural planning of these procedures which has increased the need for competent IPs and APs with specific expertise and dedicated training in SHD (10,23–27). Furthermore, the role of CCT in newer technologies such as left atrial appendage (LAA) occlusion device implantation and the systematic evaluation of left ventricular assist devices (LVADs) continues to expand due to the distinct advantages from a spatial resolution perspective (28–31). Within the realm of transcatheter mitral valve replacement (TMVR), pre procedural CCT is a requirement in device se-

lection, left ventricular outflow tract obstruction prediction risk, and intraprocedural fusion road mapping (27,32,33).

The application of CCT in structural heart disease is not significantly addressed in any prior societal training guidelines (26). However, it is important that all IP and

---

Table 3: Minimum Case Volumes for Demonstration of Independent Practitioner and Advanced Practitioner Competencies

	Independent Practitioner*	Advanced Practitioner
Duration of training (Weeks)	8**	24**
Minimum number of mentored examinations involved directly with patient preparation, data acquisition and image reconstruction***	65	150
Minimum number of mentored examinations interpreted	250	450

* Based on American College of Cardiology 2015 COCATS IV Document for Level II Competency.

** The time frame of 8 and 24 weeks do not need to be consecutive. It is possible for trainees in high volume centers to achieve competency in a shorter time frame provided that all milestones are achieved. Training in cardiac computed tomography may be counted as part of a dedicated multimodality cardiac imaging training experience.

*** Independent Practitioner competency may include review of studies from an established teaching file, previous CCT cases, journals and/or textbooks, and electronic/online courses/continuing medical education. Trainees may be present at the scanner or via telemedicine to engage directly with patient preparation, data acquisition and image reconstruction. A simulation environment may offer opportunities to supplement engagement with the recommended number of live cases.

Table 4: Minimum Case Volumes for Demonstration of Structural Heart Disease Competency*

	Independent Practitioner**	Advanced Practitioner***
Minimum number of mentored examinations involved directly with patient preparation, data acquisition and image reconstruction	10	30
Minimum number of mentored examinations interpreted to include, but not limited to: • TAVR (including Valve-in-Valve) • LAA Closure • TMVR • ASD/PFO Closure • Paravalvular Leak • Ventricular Assist Device	50	100

* While case volume and didactics can provide an initial training experience, demonstrated Independent (IP) and Advanced Practitioner (AP) competency in structural heart disease requires engagement at an institution with a multispecialty heart team.

** Emphasis for Independent Practitioner includes achieving basic competency in uncomplicated TAVR planning with exposure to the other clinical scenarios.

*** Demonstration of Advanced Practitioner Structural Heart Competency may not be sufficient for the comprehensive, expert level practice of all complex structural heart imaging studies, such as, but not limited to TMVR, paravalvular leak and other high-risk structural procedures.

Trainees are also directed to Table 8 for a discussion on potential future curriculum competencies in this rapidly evolving field.

Table 5: Minimum Case Volumes for Demonstration of Congenital Heart Disease Competency*

	Independent Practitioner**	Advanced Practitioner***
Minimum number of mentored examinations involved directly with patient preparation, data acquisition and image reconstruction	10	20
Minimum number of mentored examinations interpreted • Simple Congenital • Complex Congenital	20	50*

* While case volume and didactics can provide an initial training experience, demonstrated Independent Practitioner and Advanced Practitioner competency in congenital heart disease requires engagement at an institution with expertise in the unique care needs of patients with congenital heart disease.

** Emphasis for Independent Practitioner is achieving basic competency in simple congenital heart disease with exposure to complex congenital heart disease.

*** Demonstration of Advanced Practitioner Congenital Heart Disease Competency may not be sufficient for the comprehensive, expert level practice of all complex congenital heart cardiac CT imaging.
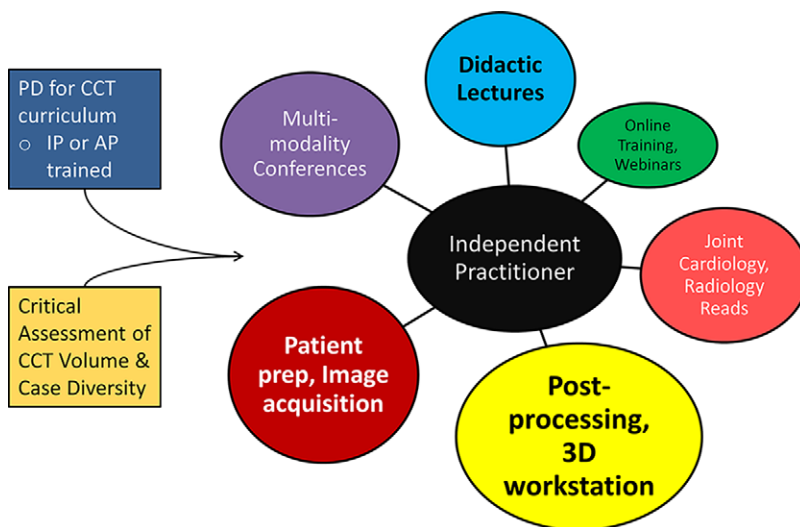
Figure 2: Comprehensive Independent Practitioner Training Curriculum in CCT The CCT PD must have attained IP status and critically evaluated individual institution case volume, case diversity, supervisor expertise, and trainee needs prior to curriculum planning. Key components of IP training are highlighted in various shading: postprocessing, 3D workstation image manipulation, patient preparation, image acquisition, and didactics. Online training and webinars may be needed to supplement local resources, particularly in low volume institutions.

AP trainees receive at least introductory exposure to this field with didactic content incorporating learning objectives from Table 2 including an understanding of vascular access. While case volume and didactics can provide an initial training experience to structural heart disease, more advanced training requires dedicated time with regular attendance at multi-specialty heart team conferences to fully understand the procedure, potential complications/pitfalls, and minimum equipment requirements as part of a 360-degree learning experience. Multi-specialty "heart team" conferences typically include an expert in CCT imaging, interventional cardiology, cardiothoracic (CT) surgery, interventional imagers, cardiac anesthesia, and other members of the cardiovascular team.

Congenital Heart Disease (CHD)

CCT provides detailed information on the anatomy of the entire thorax and, in contrast to other modalities, is superior for evaluating vascular/soft tissue structures in the setting of CHD (34). While true expertise in the nuances of congenital heart disease require specific training and time dedicated to this area, all IP and AP trainees should have a robust understanding of the distinct advantages/limitations of CCT, as well as other imaging technologies, as part of a multimodality approach to CHD. IP trainees, and more importantly AP trainees, should spend significant time with protocol development and image acquisition as part of the CHD curriculum as standardized coronary protocols may not adequately answer the clinical question (35,36). Additionally, a robust didactic curriculum utilizing learning objectives from Table 2 provide a needed knowledge foundation of simple and complex congenital lesions and repairs. It is strongly encouraged to further solidify these learning objectives in a multispecialty setting involving case review with adult CHD specialist or pediatric cardiologist, other noninvasive imaging specialists (particularly echocardiography and cardiac MR), and a congenital heart disease surgeon, when available. In addition to increasing medical knowledge and improving patient care among trainees, multispecialty learning opportunities teach effective communication skills among members of the CHD team.

Functional Testing of Ischemic Heart Disease

In addition to CCT's ability to diagnose coronary atherosclerosis anatomically, there are emerging CCT applications that allow for functional assessment of ischemia, most notably CT perfusion (CTP) and CT-based fractional flow reserve (FFR-CT) (37). Ideally, a multidisciplinary heart team conference will leverage local expertise among CCT, nuclear cardiology, cardiac MR, echocardiography, and interventional cardiology to provide a valuable forum for open discussion on strengths, weaknesses, and appropriate use of the respective modalities (38). Table 2 outlines important learning objectives pertaining to functional assessment by CCT. In general, both IP and AP trainees should demonstrate understanding of the current clinical role, supporting data, techniques, strengths, and weaknesses of CT-based techniques for functional assessment of CAD lesions, and how these tests may compare with other imaging techniques. As many training centers may not have readily

available access to specific functional CT techniques, including CTP or FFR-CT, hands-on experience during training is not required to meet competency objectives for IP or AP trainees.

Didactic Curriculum

While a large proportion of the IP & AP training curriculum can be administered in conjunction with live case review, a full didactic curriculum is vital to supplement where gaps in training supervisor or case diversity exist. A didactic curriculum should incorporate multispecialty lectures from local experts complimented with webinars, societal educational offerings, and attendance at annual scientific meetings. Figures 2 and 3 highlight the comprehensive, multifaceted approach that is needed to meet the needs of an IP and AP learner in the current era of CCT. Table 6 lists supplemental reading of societal guidelines, appropriate use criteria and key articles germane to an understanding of CCT for IP and AP trainees. Online training, webinars and simulation

environments may be a useful learning adjunct in lower volume or smaller programs to supplement lower volume centers and less common CCT applications.
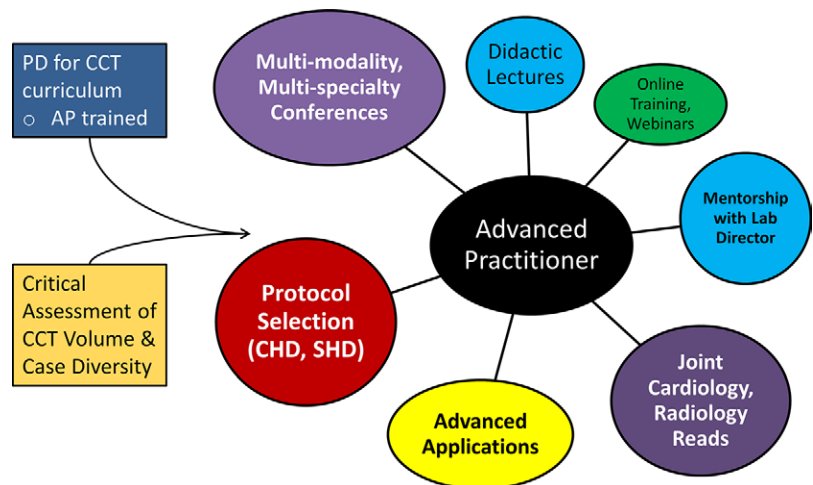
Figure 3: Comprehensive Advanced Practitioner Training Curriculum in CCT. AP training builds on IP skills, but pivots toward more complex applications of CCT and more complex cardiac disease. Integration of multidisciplinary resources into training by leveraging the advanced skills of both cardiology and radiology is needed. Direct trainee mentorship by the laboratory director or other AP supervisor is also imperative.

Table 6: Recommended Supplementary Reading for Independent Practitioner & Advanced Practitioner Curriculum

Topic	Article
Appropriate Use Criteria	Taylor et al (39)–Multisociety/SCCT 2010 Appropriate Use Criteria for Cardiac Computed Tomography
	White et al (40)–Multisociety/SCCT 2013 Appropriate Utilization of Cardiovascular Imaging in Heart Failure.
	Wolk et al (2)–Multisociety/SCCT 2013 Multimodality Appropriate Use Criteria for the Detection and Risk Assessment of Stable Ischemic Heart Disease
	Rybicki et al (41)–Multisociety/SCCT 2015 Appropriate Utilization of Cardiovascular Imaging in Emergency Department Patients with Chest Pain.
	Bonow RO et al (10)–Multisociety/SCCT 2017 Appropriate Use Criteria for the Treatment of Patients with Severe Aortic Stenosis
	Doherty JU et al (24)–Multisociety/SCCT 2017 Appropriate Use Criteria for Multimodality Imaging in Valvular Heart Disease
	Patel et al (42)–Multisociety/SCCT 2017 Appropriate Use Criteria for Coronary Revascularization in Patients with Stable Ischemic Heart Disease
	Sachdeva, et al (43)–Multisociety/SCCT 2020 Appropriate Use Criteria for Multimodality Imaging During the Follow-up Care of Patients with Congenital Heart Disease
Curriculum Development	Maroules et al (17)–2015 SCCT Curriculum Guidelines for General (Level 1) Cardiovascular CT Training
	Garcia et al (12)–2015 ACC COCATS 4 Task Force 7: Training in Cardiovascular Computed Tomography Imaging
	2016 ACR-NASCI-SPR (13) Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography
CCT Acquisition, Interpretation and Reporting	Abbara S et al (44)–SCCT guidelines for the performance and acquisition of coronary computed tomographic angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee Endorsed by the North American Society for Cardiovascular Imaging (NASCI)
	Cury et al (45)–CAD-RADS Coronary Artery Disease-Reporting and Data System
	Thomas et al (46)–Management of Coronary Artery Calcium and Coronary CTA Findings
	Truong et al (47)–Coronary computed tomography in women: An expert consensus statement from the SCCT
	Choi et al–SCCT guidance for use of CCT Amid the COVID-19 pandemic: Endorsed by the American College of Cardiology (48)

Table 6 (continues)

Table 6 (*continued*): Recommended Supplementary Reading for Independent Practitioner & Advanced Practitioner Curriculum

Topic	Article
Coronary Calcium	Hecht HS et al (49)-2016 SCCT/STR guidelines for coronary artery calcium scoring of noncontrast noncardiac chest CT scans: A report of the SCCT and Society of Thoracic Radiology
	Hecht HS et al (50)–Clinical indications for coronary artery calcium scoring in asymptomatic patients: Expert consensus statement from the SCCT
	Hecht HS et al (51)–CAC-DRS: Coronary Artery Calcium Data and Reporting System. An expert consensus document of the SCCT
	Grundy SM et al (52)–2018 Multisociety Guideline on the Management of Blood cholesterol: A report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines
	2019 ESC/EAS guidelines (53) for the management of dyslipiademias: lipid modification to reduce cardiovascular risk
	Arnett DK et al (54)–2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the ACC/AHA Task Force on Clinical Practice Guidelines
Coronary Artery Disease Pathology and Guidelines	Budoff et al (55)–Assessment of Coronary Artery Disease by Cardiac Computed Tomography
	Leipsic et al (56)–SCCT guidelines for the interpretation and reporting of coronary CT angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee
	National Institute for Health and Care Excellence (NICE) guidelines (4): Chest pain of recent onset: assessment and diagnosis
	Knuuti J et al (3) 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes
Structural Heart Disease	Blanke et al (25)–Computed tomography imaging in the context of transcatheter aortic valve implantation (TAVI)/TAVR: An expert consensus document of the SCCT
	Leipsic et al (57)–ACR Appropriateness Criteria Imaging for Transcatheter Aortic Valve Replacement
	Blanke et al (32)–Mitral Annular Evaluation with CT in the Context of Transcatheter Mitral Valve Replacement
	Buttan et al (58)–Evaluation of Valvular Disease by Cardiac Computed Tomography Assessment
	Rizvi et al (59)–Analysis of Ventricular Function by CT
	Ismail et al (28)–CT imaging for left atrial appendage closure: a review and pictorial essay
	Carr et al (29)–CT of Left Ventricular Assist Devices
	Korsholm et al (30)–Expert Recommendations on Cardiac Computed Tomography for Planning Transcatheter Left Atrial Appendage Occlusion
	Leipsic et al (27) Core Competencies in Cardiac CT for Imaging Structural Heart Disease Interventions: An Expert Consensus Statement
Congenital Heart Disease	Han et al (35,36)–Computed Tomography Imaging in Patients with Congenital Heart Disease Part 1&2
Ischemic Testing with CCT	Rabbat et al (60)–Interpreting results of coronary computed tomography angiography-derived fractional flow reserve in clinical practice
	Ramsey BC (61)–Myocardial Assessment with Cardiac CT: Ischemic Heart Disease and Beyond
	Schuijf et al (37)–Fractional flow reserve and myocardial perfusion by computed tomography: a guide to clinical application
	Singh et al. The role of computed tomography myocardial perfusion imaging in clinical practice (62).
	Patel et al (63) SCCT expert consensus document on myocardial computed tomography perfusion imaging.
	Nicol et al. The Future of Cardiovascular Computed Tomography: Advanced Analytics and Clinical Insights (64)
Vascular CT	Kramer et al (65)–ACCF/AHA 2007 Clinical Competence Statement on Vascular Imaging with Computed Tomography and Magnetic Resonance
	Murphy et al (66)–Vascular CT and MRI: a practical guide to imaging protocols
	Dave et al (67)–Computed Tomography Angiography of the Upper Extremity
	Scheske et al (68)–Computed Tomography Angiography of the Thoracic Aorta
	Hansen NJ (69)–Computed Tomography Angiography of the Abdominal Aorta
	Raman et al (70)–Computed Tomography Angiography of the Small Bowel and Mesentery
	Falesch et al (71)–Computed Tomography Angiography of the Renal Circulation
	Cook TS (72)–Computed Tomography Angiography of the Lower Extremities

Table 7: Suggested Independent Practitioner & Advanced Practitioner Trainee Quality Improvement (QI) Projects

Initiation Step	Question To Be Investigated	Possible Intervention	Possible Indicator of Impact
Clinical information and order entry	Are the CCT studies appropriate for the intended clinical question?	Increasing awareness about appropriateness criteria for CCT by discussion, lectures and multidisciplinary meetings	Decrease in incorrectly ordered studies
Patient preparation	Are pharmaceutical agents appropriately used for patient preparation based on local CCT scanner technology?	Educating the CCT trainees, CT technologists, and nurses regarding the use of pharmaceutical agents and develop an algorithm	Near 0% nondiagnostic studies due to suboptimal heart rate control or patient preparation
Acquisition or protocol	o Is the utilization of prospective and retrospective ECG-gating appropriate for the clinical question? o What is the understanding of various CT artifacts that can be fixed by postprocessing like ECG-gating artifacts?	Educating the CCT trainees and CT technologists regarding appropriate patient selection, ECG-gating, CCT protocols, and ECG-gating artifacts and develop an algorithm	Near 0% of studies repeated due to improper protocol selection or ECG-gating related artifact
Image display	Is multiplanar and centerline analysis being routinely performed for evaluation of coronary artery anatomy and disease?	Implement standardized best-practices for interpretation using centerline and multiplanar analysis	<5% interobserver variability with respect to stenosis severity grading
Interpretation	What is the adherence to standardized reporting system?	Implement standardized reporting utilizing CAD RADS	Increased compliance with reporting utilizing CAD RADS recommendations
Communication	o Does the CCT report communicate findings to the ordering physicians in a clear and consistent fashion? o Does the CCT report make suggestions for further management?	Implement standardized reporting utilizing CAD RADS, including any recommendations for downstream testing or medical intervention	o Increased compliance with guideline-based primary prevention therapy o Increased appropriate ischemic testing, revascularization o Decreased normal, nonobstructive invasive angiograms
Radiation Dose Monitoring and Reporting	Are radiation dose reduction principles being applied to CCT scans by accreditation standards while maintaining appropriate diagnostic quality?	Implement a body-mass index based protocol to apply dose sparing techniques such as reduced scan range, reduced kV imaging and iterative reconstruction	Measure and reduce measured radiation dose by 30%

Advanced Practitioner Training

With respect to the AP trainee curriculum (Fig 3), the didactic training focus should pivot toward more complex applications of CCT and complex cardiac disease. Additionally, a broader focus on integrating into a multidisciplinary team and leveraging the advanced skills of both cardiology and radiology is needed. Finally, a comprehensive AP curriculum should involve direct mentorship by the laboratory director or other AP supervisors so that education in the business and administrative aspects of leading a CCT laboratory are incorporated. AP trainees, in addition to a comprehensive understanding of the learning objectives, require a curriculum incorporating mentorship opportunities with the laboratory director. This could include involvement with new equipment purchases, personnel management, protocol develop-ment, and performance improvement (PI)/quality assessment (QA). Particularly with the changing landscape of medical reimbursement and payer structures, a strong foundation in quality and appropriate use is vital to a future laboratory director or PD. Specific to the ACGME, requirements have been put in place for residencies and fellowships to actively participate in PI or QA projects as part of graduation requirements. Table 7 lists several recommendations for CCT-specific QA/PI projects.

Summary

The rapid growth and expansion of CCT requires training programs to adopt a comprehensive training curriculum in order to meet the growing need for IP and AP that possess a minimum experience and core understanding of all

Table 8: Potential Future Curriculum Competencies in Cardiac CT Utilizing Emerging Technologies and Clinical Indications

Hardware Advancements
Photon Counting Detectors
Novel contrast agents
Hybrid CT and nuclear imaging of atherosclerosis

Advanced Coronary Artery Analysis
Work-station based computational fluid dynamics
Machine learning and radiomics aided plaque quantification
Machine learning aided personalized risk prediction with CTA and clinical datasets
Advancements in perivascular fat attenuation
Endothelial Shear stress calculation
Virtual stent planning

Advanced Myocardial Analysis
CT strain imaging
CT based extracellular volume
Dynamic stress myocardial perfusion

Advanced Structural Planning
CT based valve hemodynamic assessment
Application of CT derived risk score in structural planning
Tricuspid valve intervention planning
Improved understanding of post valve implant leaflet thrombosis
CT in virtual reality planning

Novel Clinical Indications
Acute coronary syndromes
Calcium imaging in higher risk populations
Atherosclerosis evaluation in younger adults
CT integration with genetics and genomics
CT in cardio-oncology
Application of CT in new clinical guidelines
Enhanced integration training and practice through telemedicine and simulation environments

ACR, COCATS 4 and other global documents, to develop a training experience that produces a more uniform level of competence for both cardiology and radiology trainees. Additionally, better baseline training in CCT may promote more appropriate implementation of CCT into clinical practice after graduation and/or encourage more trainees to pursue advanced fellowships in CCT.

References

1. Al-Mallah MH, Aljizeeri A, Villines TC, Srichai MB, Alsaileek A. Cardiac computed tomography in current cardiology guidelines. J Cardiovasc Comput Tomogr 2015;9(6):514–523.
2. Wolk MJ, Bailey SR, Doherty JU, et al. ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS 2013 multimodality appropriate use criteria for the detection and risk assessment of stable ischemic heart disease: a report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. J Am Coll Cardiol 2014;63(4):380–406.
3. Knuuti J, Wijns W, Saraste A, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. Eur Heart J 2020;41(3):407–477.
4. National Institute for Health and Care Excellence. Chest pain of recent onset: assessment and diagnosis. London, England: National Institute for Health and Care Excellence, 2016.
5. Kelion AD, Nicol ED. The rationale for the primacy of coronary CT angiography in the National Institute for Health and Care Excellence (NICE) guideline (CG95) for the investigation of chest pain of recent onset. J Cardiovasc Comput Tomogr 2018;12(6):516–522.
6. Dreisbach JG, Nicol ED, Roobottom CA, Padley S, Roditi G. Challenges in delivering computed tomography coronary angiography as the first-line test for stable chest pain. Heart 2018;104(11):921–927.
7. Shaw LJ, Blankstein R, Jacobs JE, et al. Defining Quality in Cardiovascular Imaging: A Scientific Statement From the American Heart Association. Circ Cardiovasc Imaging 2017;10(12):10.
8. Spilberg G, Scholtz JE, Hoffman U, et al. Availability and Location of Cardiac CT and MR Services in Massachusetts. J Am Coll Radiol 2018;15(4):618–621.
9. Arnett DK, Blumenthal RS, Albert MA, et al. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol 2019;74(10):e177–e232 [Published corrections appear in J Am Coll Cardiol 2019;74(10):1429–1430 and J Am Coll Cardiol 2020;75(7):840.].

aspects of CCT. As new technologies continue to emerge (Table 8) with sufficient evidence for efficacy and meaningful impact on clinical management, it is expected that the curricular needs of trainees will evolve. The core elements of this document are expected to remain foundational for IP and AP competency, while future updates to this training curriculum may be issued through both traditional and emerging digital publication formats. A curriculum based solely on case volume is insufficient to bridge the substantial knowledge gap, particularly among IP graduates given the diversity of training backgrounds, local volume, and supervisor expertise and so the recommended case volumes serve as a minimum floor to assess competency. To build from the 2015 SCCT Level I Curriculum Guideline, we encourage adoption of these training curriculum recommendations as a supplement to the current societal statements that include

10. Bonow RO, Brown AS, Gillam LD, et al. ACC/AATS/AHA/ASE/EACTS/ HVS/SCA/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for the Treatment of Patients With Severe Aortic Stenosis: A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, European Association for Cardio-Thoracic Surgery, Heart Valve Society, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. J Am Coll Cardiol 2017;70(20):2566–2598.

11. Blanke P, Weir-McCall JR, Achenbach S, et al. Computed tomography imaging in the context of transcatheter aortic valve implantation (TAVI) / transcatheter aortic valve replacement (TAVR): An expert consensus document of the Society of Cardiovascular Computed Tomography. J Cardiovasc Comput Tomogr 2019;13(1):1–20.

12. Garcia MJ, Blankstein R, Budoff MJ, et al. COCATS 4 Task Force 7: Training in Cardiovascular Computed Tomographic Imaging. J Am Coll Cardiol 2015;65(17):1810–1821.

13. American College of Radiology. North American Society of Cardiovascular Imaging (NASCI), and the Society of Pediatric Radiology (SPR) Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography (CT) - Resolution 21 (2016). Reston, Va: American College of Radiology, 2016.

14. Royal College of Radiologists, Royal College of Physicians, British Society of Cardiovascular Imaging. Standards of practice of computed tomography coronary angiography (CTCA) in adult patients. 2014.

15. Nieman K, Achenbach S, Pugliese F, Cosyns B, Lancellotti P, Kitsiou A. Cardiac computed tomography core syllabus of the European Association of Cardiovascular Imaging (EACVI). Eur Heart J Cardiovasc Imaging 2015;16(4):351–352.

16. Royal College of Radiologists. Clinical Radiology: 2020 Specialty Training Curriculum. London, England: Royal College of Radiologists, 2020.

17. Maroules CD, Cheezum MK, Joshi PH, et al. SCCT curriculum guidelines for general (level 1) cardiovascular CT training. J Cardiovasc Comput Tomogr 2015;9(2):81–88.

18. Parwani P, Lopez-Mattei J, Choi AD. Building Bridges in Cardiology and Radiology: Why Collaboration Is the Future of Cardiovascular Imaging. J Am Coll Cardiol 2018;72(20):2534–2538.

19. American College of Radiology. ACR CT Accreditation Program Requirements. Reston, Va: American College of Radiology, 2015.

20. Fuster V, Halperin JL, Williams ES, et al. COCATS 4 Task Force 1: Training in Ambulatory, Consultative, and Longitudinal Cardiovascular Care. J Am Coll Cardiol 2015;65(17):1734–1753.

21. Joint Royal College of Physicians Training Board. Specialty Training Curriculum for Cardiology.

22. Taylor AJ, Patrick J, Abbara S, et al. Relationship between previous training and experience and results of the certification examination in cardiovascular computed tomography. JACC Cardiovasc Imaging 2010;3(9):976–980.

23. Achenbach S, Delgado V, Hausleiter J, Schoenhagen P, Min JK, Leipsic JA. SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). J Cardiovasc Comput Tomogr 2012;6(6):366–380.

24. Doherty JU, Kort S, Mehran R, Schoenhagen P, Soman P. ACC/AATS/ AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for Multimodality Imaging in Valvular Heart Disease: A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. J Am Coll Cardiol 2017;70(13):1647–1672.

25. Blanke P, Weir-McCall JR, Achenbach S, et al. Computed Tomography Imaging in the Context of Transcatheter Aortic Valve Implantation (TAVI)/ Transcatheter Aortic Valve Replacement (TAVR): An Expert Consensus Document of the Society of Cardiovascular Computed Tomography. JACC Cardiovasc Imaging 2019;12(1):1–24.

26. Wang DD, Geske J, Choi AD, et al. Navigating a Career in Structural Heart Disease Interventional Imaging. JACC Cardiovasc Imaging 2018;11(12):1928–1930.

27. Leipsic J, Nørgaard BL, Khalique O, et al. Core Competencies in Cardiac CT for Imaging Structural Heart Disease Interventions: An Expert Consensus Statement. JACC Cardiovasc Imaging 2019;12(12):2555–2559.

28. Ismail TF, Panikker S, Markides V, et al. CT imaging for left atrial appendage closure: a review and pictorial essay. J Cardiovasc Comput Tomogr 2015;9(2):89–102.

29. Carr CM, Jacob J, Park SJ, Karon BL, Williamson EE, Araoz PA. CT of left ventricular assist devices. RadioGraphics 2010;30(2):429–444.

30. Korsholm K, Berti S, Iriart X, et al. Expert Recommendations on Cardiac Computed Tomography for Planning Transcatheter Left Atrial Appendage Occlusion. JACC Cardiovasc Interv 2020;13(3):277–292.

31. Wang DD, Eng M, Kupsky D, et al. Application of 3-Dimensional Computed Tomographic Image Guidance to WATCHMAN Implantation and Impact on Early Operator Learning Curve: Single-Center Experience. JACC Cardiovasc Interv 2016;9(22):2329–2340.

32. Blanke P, Dvir D, Cheung A, et al. Mitral Annular Evaluation With CT in the Context of Transcatheter Mitral Valve Replacement. JACC Cardiovasc Imaging 2015;8(5):612–615.

33. Wang DD, Eng MH, Greenbaum AB, et al. Validating a prediction modeling tool for left ventricular outflow tract (LVOT) obstruction after transcatheter mitral valve replacement (TMVR). Catheter Cardiovasc Interv 2018;92(2):379–387.

34. Han BK, Casey S, Witt D, et al. Development of a congenital cardiovascular computed tomography imaging registry: Rationale and implementation. J Cardiovasc Comput Tomogr 2018;12(3):263–266.

35. Han BK, Rigsby CK, Hlavacek A, et al. Computed Tomography Imaging in Patients with Congenital Heart Disease Part I: Rationale and Utility. An Expert Consensus Document of the Society of Cardiovascular Computed Tomography (SCCT): Endorsed by the Society of Pediatric Radiology (SPR) and the North American Society of Cardiac Imaging (NASCI). J Cardiovasc Comput Tomogr 2015;9(6):475–492.

36. Han BK, Rigsby CK, Leipsic J, et al. Computed Tomography Imaging in Patients with Congenital Heart Disease, Part 2: Technical Recommendations. An Expert Consensus Document of the Society of Cardiovascular Computed Tomography (SCCT): Endorsed by the Society of Pediatric Radiology (SPR) and the North American Society of Cardiac Imaging (NASCI). J Cardiovasc Comput Tomogr 2015;9(6):493–513.

37. Schuijf JD, Ko BS, Di Carli MF, et al. Fractional flow reserve and myocardial perfusion by computed tomography: a guide to clinical application. Eur Heart J Cardiovasc Imaging 2018;19(2):127–135.

38. Cavalcante R, Onuma Y, Sotomi Y, et al. Non-invasive Heart Team assessment of multivessel coronary disease with coronary computed tomography angiography based on SYNTAX score II treatment recommendations: design and rationale of the randomised SYNTAX III Revolution trial. EuroIntervention 2017;12(16):2001–2008.

39. Taylor AJ, Cerqueira M, Hodgson JM, et al. ACCF/SCCT/ACR/AHA/ASE/ ASNC/NASCI/SCAI/SCMR 2010 Appropriate Use Criteria for Cardiac Computed Tomography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance. J Cardiovasc Comput Tomogr 2010;4(6):407.e1–407.e33, e1–e33.

40. White RD, Patel MR, Abbara S, et al. 2013 ACCF/ACR/ASE/ASNC/SCCT/ SCMR appropriate utilization of cardiovascular imaging in heart failure: an executive summary: a joint report of the ACR Appropriateness Criteria ® Committee and the ACCF Appropriate Use Criteria Task Force. J Am Coll Radiol 2013;10(7):493–500.

41. Emergency Department Patients With Chest Pain Writing Panel; Rybicki FJ, Udelson JE, et al. 2015 ACR/ACC/AHA/AATS/ACEP/ASNC/NASCI/ SAEM/SCCT/SCMR/SCPC/SNMMI/STR/STS Appropriate Utilization of Cardiovascular Imaging in Emergency Department Patients With Chest Pain: A Joint Document of the American College of Radiology Appropriateness Criteria Committee and the American College of Cardiology Appropriate Use Criteria Task Force. J Am Coll Radiol 2016;13(2):e1–e29.

42. Patel MR, Calhoon JH, Dehmer GJ, et al. ACC/AATS/AHA/ASE/ASNC/ SCAI/SCCT/STS 2017 Appropriate Use Criteria for Coronary Revascularization in Patients With Stable Ischemic Heart Disease: A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and Society of Thoracic Surgeons. J Am Coll Cardiol 2017;69(17):2212–2241 [Published correction appears in J Am Coll Cardiol 2018;71(19):2279–2280.].

43. Sachdeva R, Valente AM, Armstrong AK, et al. ACC/AHA/ASE/HRS/ ISACHD/SCAI/SCCT/SCMR/SOPE 2020 Appropriate Use Criteria for Multimodality Imaging During the Follow-Up Care of Patients With Congenital Heart Disease: A Report of the American College of Cardiology Solution Set Oversight Committee and Appropriate Use Criteria Task Force,

American Heart Association, American Society of Echocardiography, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Pediatric Echocardiography. J Am Coll Cardiol 2020;75(6):657–703.

44. Abbara S, Blanke P, Maroules CD, et al. SCCT guidelines for the performance and acquisition of coronary computed tomographic angiography: A report of the society of Cardiovascular Computed Tomography Guidelines Committee: Endorsed by the North American Society for Cardiovascular Imaging (NASCI). J Cardiovasc Comput Tomogr 2016;10(6):435–449.

45. Cury RC, Abbara S, Achenbach S, et al. CAD-RADS(TM) Coronary Artery Disease - Reporting and Data System. An expert consensus document of the Society of Cardiovascular Computed Tomography (SCCT), the American College of Radiology (ACR) and the North American Society for Cardiovascular Imaging (NASCI). Endorsed by the American College of Cardiology. J Cardiovasc Comput Tomogr 2016;10(4):269–281.

46. Thomas DM, Divakaran S, Villines TC, et al. Management of Coronary Artery Calcium and Coronary CTA Findings. Curr Cardiovasc Imaging Rep 2015;8(6):18.

47. Truong QA, Rinehart S, Abbara S, et al. Coronary computed tomographic imaging in women: An expert consensus statement from the Society of Cardiovascular Computed Tomography. J Cardiovasc Comput Tomogr 2018;12(6):451–466.

48. Choi AD, Abbara S, Branch KR, et al. Society of Cardiovascular Computed Tomography guidance for use of cardiac computed tomography amidst the COVID-19 pandemic. Endorsed by the American College of Cardiology. J Cardiovasc Comput Tomogr 2020;14(2):101–104.

49. Hecht HS, Cronin P, Blaha MJ, et al. 2016 SCCT/STR guidelines for coronary artery calcium scoring of noncontrast noncardiac chest CT scans: A report of the Society of Cardiovascular Computed Tomography and Society of Thoracic Radiology. J Cardiovasc Comput Tomogr 2017;11(1):74–84 [Published correction appears in J Cardiovasc Comput Tomogr 2017;11(2):170.].

50. Hecht H, Blaha MJ, Berman DS, et al. Clinical indications for coronary artery calcium scoring in asymptomatic patients: Expert consensus statement from the Society of Cardiovascular Computed Tomography. J Cardiovasc Comput Tomogr 2017;11(2):157–168.

51. Hecht HS, Blaha MJ, Kazerooni EA, et al. CAC-DRS: Coronary Artery Calcium Data and Reporting System. An expert consensus document of the Society of Cardiovascular Computed Tomography (SCCT). J Cardiovasc Comput Tomogr 2018;12(3):185–191.

52. Grundy SM, Stone NJ, Bailey AL, et al. 2018 AHA/ACC/AACVPR/AAPA/ABC/ACPM/ADA/AGS/APhA/ASPC/NLA/PCNA Guideline on the Management of Blood Cholesterol: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol 2019;73(24):3168–3209.

53. Authors/Task Force Members; ESC Committee for Practice Guidelines (CPG); ESC National Cardiac Societies. 2019 ESC/EAS guidelines for the management of dyslipidaemias: Lipid modification to reduce cardiovascular risk. Atherosclerosis 2019;290:140–205 [Published corrections appear in Atherosclerosis 2020;292:160–162 and Atherosclerosis 2020;294:80–82.].

54. Arnett DK, Blumenthal RS, Albert MA, et al. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation 2019;140(11):e596–e646.

55. Budoff MJ, Achenbach S, Blumenthal RS, et al. Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation 2006;114(16):1761–1791.

56. Leipsic J, Abbara S, Achenbach S, et al. SCCT guidelines for the interpretation and reporting of coronary CT angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee. J Cardiovasc Comput Tomogr 2014;8(5):342–358.

57. Expert Panel on Cardiac Imaging and Vascular Imaging; Leipsic JA, Blanke P, et al. ACR Appropriateness Criteria® Imaging for Transcatheter Aortic Valve Replacement. J Am Coll Radiol 2017;14(11S):S449–S455.

58. Buttan AK, Yang EH, Budoff MJ, Vorobiof G. Evaluation of valvular disease by cardiac computed tomography assessment. J Cardiovasc Comput Tomogr 2012;6(6):381–392.

59. Rizvi A, Deaño RC, Bachman DP, Xiong G, Min JK, Truong QA. Analysis of ventricular function by CT. J Cardiovasc Comput Tomogr 2015;9(1):1–12.

60. Rabbat MG, Berman DS, Kern M, et al. Interpreting results of coronary computed tomography angiography-derived fractional flow reserve in clinical practice. J Cardiovasc Comput Tomogr 2017;11(5):383–388.

61. Ramsey BC, Fentanes E, Choi AD, Branch KR, Thomas DM. Myocardial Assessment with Cardiac CT: Ischemic Heart Disease and Beyond. Curr Cardiovasc Imaging Rep 2018;11(7):16.

62. Singh A, Mor-Avi V, Patel AR. The role of computed tomography myocardial perfusion imaging in clinical practice. J Cardiovasc Comput Tomogr 2020;14(2):185–194.

63. Patel AR, Bamberg F, Branch K, et al. Society of cardiovascular computed tomography expert consensus document on myocardial computed tomography perfusion imaging. J Cardiovasc Comput Tomogr 2020;14(1):87–100.

64. Nicol ED, Norgaard BL, Blanke P, et al. The Future of Cardiovascular Computed Tomography: Advanced Analytics and Clinical Insights. JACC Cardiovasc Imaging 2019;12(6):1058–1072.

65. Kramer CM, Budoff MJ, Fayad ZA, et al. ACCF/AHA 2007 clinical competence statement on vascular imaging with computed tomography and magnetic resonance. A report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. J Am Coll Cardiol 2007;50(11):1097–1114.

66. Murphy DJ, Aghayev A, Steigner ML. Vascular CT and MRI: a practical guide to imaging protocols. Insights Imaging 2018;9(2):215–236.

67. Dave RB, Fleischmann D. Computed Tomography Angiography of the Upper Extremities. Radiol Clin North Am 2016;54(1):101–114.

68. Scheske JA, Chung JH, Abbara S, Ghoshhajra BB. Computed Tomography Angiography of the Thoracic Aorta. Radiol Clin North Am 2016;54(1):13–33.

69. Hansen NJ. Computed Tomographic Angiography of the Abdominal Aorta. Radiol Clin North Am 2016;54(1):35–54.

70. Raman SP, Fishman EK. Computed Tomography Angiography of the Small Bowel and Mesentery. Radiol Clin North Am 2016;54(1):87–100.

71. Falesch LA, Foley WD. Computed Tomograpy Angiography of the Renal Circulation. Radiol Clin North Am 2016;54(1):71–86.

72. Cook TS. Computed Tomography Angiography of the Lower Extremities. Radiol Clin North Am 2016;54(1):115–130.