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Guidelines/Consensus statement

Competency based curriculum for cardiovascular magnetic resonance: A position statement of the Society for Cardiovascular Magnetic Resonance☆

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ABSTRACT

This position statement guides cardiovascular magnetic resonance (CMR) imaging program directors and learners on the key competencies required for Level II and III CMR practitioners, whether trainees come from a radiology or cardiology background. This document is built upon existing curricula and was created and vetted by an international panel of cardiologists and radiologists on behalf of the Society for Cardiovascular Magnetic Resonance (SCMR).

1. Background and statement of purpose

Cardiovascular magnetic resonance (CMR) has seen substantial growth over the last 20 years. With an ever-increasing evidence base [1–4] coupled with improvements in scanner technology and new techniques [5–8] and evidence of cost effectiveness [9–11], international clinical practice guidelines now recommend CMR as a first-line imaging investigation for many cardiovascular conditions [12,13]. As the indications for CMR increase, the contemporary cardiac imager needs to have the appropriate clinical knowledge and technical skills to

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deliver consistently high-quality CMR examinations across an increasing range of clinical scenarios. The widening indications for CMR require an expanding and available workforce of cardiac imagers that have the basic skills for independent interpretation of CMR, and a subset of practitioners with a level of expertise to supervise trainees and to lead CMR laboratories. The SCMR guidelines for training in cardiovascular magnetic resonance [14,15] define these levels of expertise: The basic competency for CMR interpretation is referred to as Level II training - specialized training designed to provide the skills necessary to independently interpret CMR studies (also known as independent practitioner). The advanced level of expertise is referred to as Level III training - advanced training for those who aim to be responsible for the operation of a CMR laboratory and to deliver CMR training (also known as advanced practitioner).

Various other guidelines and curricula have defined minimum training requirements for interpretation of CMR at local, national, and international levels [16]. These documents are designed to ensure that CMR practitioners receive appropriate training to effectively utilize, perform and report CMR. Whilst distinct, these recommendations have many consistent and common themes, with differences largely dependent on local factors, varying disease prevalence, availability of CMR and other imaging modalities, and the role of CMR in general and subspecialty practice. However, there is currently no comprehensive competency-based document that lists the skills needed for CMR interpretation at a basic and advanced level of expertise that can be globally applied, which is the primary goal of this document.

Accordingly, this curriculum document aims to assist Program Leads/Directors in creating or implementing a CMR training program. It provides a framework of key basic training objectives to enable practitioners to successfully interpret CMR studies after completion of the program, and a framework of training objectives recommended to achieve advanced training in CMR. The SCMR curriculum suggests competency-based training with a final program evaluation. This guidance is intended to be comprehensive and globally relevant. Additionally, the document discusses inherent differences in previous training curricula from different specialties and suggests an approach to harmonize these.

To ensure diverse representation and perspectives, the writing group for this position statement was chosen in accordance with guidance from SCMR [13], selecting members with backgrounds in radiology and cardiology, including pediatric cardiology, and an established expertise in CMR education. Each member conducted a literature search within local national curricula and education documents, which were then shared and reviewed by the group during multiple video conferences. The document was divided into sections, with each member of the writing panel drafting a section of the document. Through consensus, the combined document and competency-based guidance were created and approved by the entire writing group. The document was then reviewed by the Scientific Documents Committee of SCMR before final approval by the society's Executive Committee.

2. Knowledge- and skill-based competency as a foundation for training of level II and level III imagers

Despite inherent differences between societies and countries, most CMR training guidelines share common elements. SCMR has previously defined three levels of training: Level I defines basic training for general practitioners in CMR methods and indications as required to refer to and use CMR in routine patient care. Level II, or Independent Practitioner (whether a cardiologist, radiologist or pediatric cardiologist), defines training for cardiac imagers to achieve the required level of expertise for independent CMR practice, including supervision, analysis and reporting of CMR typically encountered in routine daily practice, and includes a basic understanding of image optimization and MR physics. Level III or Advanced Practitioner training aims to achieve a higher level of expertise and acquired abilities that allow for management of more complex cases, including congenital heart disease. Additionally, the Level III imager should be able to create and oversee comprehensive CMR programs for clinical, educational, and research objectives, with a system in place to measure quality metrics, and to train and certify others in CMR. Level III builds upon the knowledge and skills of Level II with additional competencies listed below in Table 1.

A comprehensive list of learning objectives and outcomes based on competencies is provided in Table 2. The purpose of this table is to assist learners and program directors in navigating the extensive CMR educational content and focusing on essential concepts. Competencies are classified as 'Medical Knowledge', which includes competency in

Table 1
Key CMR competencies for level II and III cardiovascular imagers.

Training Level	Definition Based on Key Competencies Achieved
Level II (Independent Practitioner)	Describes common MR imaging sequences used for the evaluation of ventricular and valvular function, cardiac chamber and vascular anatomy, myocardial perfusion and tissue characterization, and recognizes the contraindications and risks of MRI and gadolinium-based contrast agent administration. Demonstrates an understanding of MR physics relating to how images are acquired, and factors that affect image quality such as signal-to-noise, spatial and temporal resolution and trade-offs with time of acquisition and breath hold times. Is able to supervise MR technologists and support them when technical issues with image generation arise. Understands basic aspects of MR safety including contraindications to MR, patient screening, safety of implanted devices and safety aspects relating to contrast and stress agents as well as resuscitation in the MR environment. Has good knowledge of the common indications for CMR relating to ischemic and non-ischemic cardiomyopathies, cardiac masses, pericardial diseases, valve imaging, basic congenital heart lesions and is able to optimize scan protocols to answer specific clinical questions. Understand basic cardiac physiology and the pathophysiology of common cardiovascular diseases, including their management, clinical and laboratory signs and role of other cardiovascular imaging modalities. Understands how to use a software program to analyze all common types of CMR data including ventricular function, flow assessment, parametric mapping analysis, myocardial perfusion and multi-planar reformatting of MR angiograms.
	Definition Based on Key Competencies Achieved (in addition to Level II competencies)
Level III (Advanced Practitioner)	Understands the process for laboratory accreditation including its requirements and maintenance. Demonstrates advanced knowledge and skills related to complex cases, covering the entire spectrum of CMR indications, including congenital heart disease, using general and more specifically tailored CMR scanning protocols. Has a detailed understanding of MR physics, including protocol optimization, causes and resolution of common artifacts as well as setting up efficient acquisition protocols. Maintains in depth knowledge of research and development in CMR including technological developments, clinical research, guideline indications and practice recommendations. Is able to set up and lead a clinical CMR program, build a framework/infrastructure for quality improvement of CMR, and develop educational programs and research platforms.

Table 2
Learning objectives and competencies.

Learning Objectives	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
MR Physics					
Describe the basic principles of MR image generation	X	X	X		
Define basic concepts of signal to noise ratio, spatial resolution, temporal resolution, contrast resolution, signal averaging, acquisition time, breath-hold time, image acceleration techniques, field of view, imaging matrix, cardiac and respiratory gating etc. and recognize the trade-offs that often occur during image optimization	X	X	X		
Describe what T1 and T2 times represent and what T1 or T2 weighting mean	X	X	X		
Describe the concept of black blood versus bright blood imaging and the basic pulse sequences often used in CMR such as spin echo, double inversion recovery spin echo, gradient recalled echo, steady state free precession imaging, T1-weighted spoiled gradient recalled echo, phase contrast, myocardial tagging sequences.		X	X		
List methods commonly used for fat suppression	X	X	X		
Describe how parametric mapping sequences are generated and how they may add incremental value for diagnostic certainty and prognostication		X			
List commonly used gadolinium-based contrast agents in CMR and common indications and contraindications, side effects and dosage selection based on patient weight	X	X	X		
Describe methods to optimize myocardial perfusion imaging and late gadolinium enhancement imaging and some technical challenges that may reduce image quality		X	X		
Describe various imaging sequences used for MR angiography and list methods for image optimization		X	X		
Describe the concept of 4D flow imaging and some potential clinical applications		X	X		
List common artifacts, their physical basis and common solutions for minimization	X	X	X		
Understand differences between CMR at 1.5 and 3 T	X	X	X	X	
Understand basic aspects of MR safety including contraindications to MR, patient screening, safety of implanted devices and safety aspects relating to contrast and stress agents as well as resuscitation in the MR environment	X	X	X	X	
Advanced understanding of MR safety including local rules and standard operating procedures for CMR		X	X	X	
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Clinical competencies					
Has good knowledge of cardiac and vascular anatomy and physiology	X	X	X	X	X
Have an advanced understanding of the pathophysiology of common cardiovascular diseases and detailed knowledge of their management, clinical and laboratory signs	X	X	X	X	X
Understand the basics, indications and risks of other cardiovascular imaging modalities, in particular invasive coronary angiography, echocardiography, nuclear imaging and CT	X	X	X	X	X
Have an advanced level of knowledge of other cardiovascular imaging modalities		X	X	X	X
Be familiar with the pharmacokinetics of stress agents used in CMR, their contra-indications and the risk and management of associated complications	X	X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Ischemic Heart Disease					
Describe normal coronary & myocardial anatomy	X	X	X	X	
Recognize chronic myocardial Infarction (both LV and RV) with commonly used CMR techniques (such as late gadolinium enhancement)	X	X	X	X	
Describe ventricular remodeling post chronic myocardial Infarction	X	X	X	X	
Evaluate myocardial viability with commonly used CMR techniques (such as dobutamine studies and late gadolinium enhancement), and how to apply them clinically	X	X	X	X	
Differentiate scarring secondary to myocardial infarction from other common causes using late gadolinium enhancement	X	X	X	X	
Describe the role and clinical use of stress perfusion CMR using common vasodilator agents (Adenosine, Regadenoson, Dipyridamole)	X	X	X	X	

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Table 2 (*continued*)

Learning Objectives	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Describe the role and clinical use of dobutamine stress CMR	X	X	X	X	
Interpret abnormalities of ischemia testing including 1st pass perfusion abnormalities, wall motion and microvascular dysfunction	X	X	X	X	
Describe the role and limitations of coronary imaging using CMR		X	X	X	
Describe the role of CMR in the assessment for complex device therapy	X	X	X	X	
Describe the role of CMR in the assessment of acute coronary syndromes (ACS)	X	X	X	X	
List and recognize the various types of myocardial infarction using CMR (such as embolic infarction)	X	X	X	X	
Describe the differential diagnoses using CMR for ACS (such as myocarditis, Tako-Tsubo, MINOCA)	X	X	X	X	
Describe the non-cardiac differential diagnoses using CMR for ACS (such as aortic disease, pulmonary disease)	X	X	X	X	
Describe the methods and techniques to assess myocardial edema	X	X	X	X	
Recognize the complications of myocardial infarction (such as thrombus, aneurysm formation, ventricular septal defect and mitral regurgitation)	X	X	X	X	
Describe microvascular obstruction assessment techniques using CMR and the relationship with no reflow	X	X	X	X	
Demonstrate the ability to communicate CMR findings to referring clinicians that clearly informs clinical decision making	X	X	X	X	
Contribute to multidisciplinary IHD conferences	X	X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Non-Ischemic cardiomyopathies					
Describe the utility of different CMR sequences for the evaluation of non-ischemic cardiomyopathies, including their strengths and limitations	X	X	X	X	
Recognize the main morphologic and functional phenotypes of non-ischemic cardiomyopathies and their imaging features: hypertrophic, dilated, restrictive, and arrhythmogenic cardiomyopathy	X	X	X	X	
List common non-ischemic conditions that can present with a hypertrophic phenotype	X	X	X	X	
Recognize the different phenotypes of hypertrophic cardiomyopathy (HCM) and their CMR features	X	X	X	X	
Describe the CMR findings that provide prognostic information for HCM patients		X	X	X	
Describe the CMR features of athlete's heart	X	X	X	X	
Recognize the CMR features of hypertensive heart disease	X	X	X	X	
List common non-ischemic conditions that can present with a restrictive phenotype	X	X	X	X	
Describe the typical CMR findings of cardiac amyloidosis and its different subtypes (AL, ATTR)	X	X	X	X	
Recognize the CMR features of less frequent infiltrative disease (e.g.Fabry, Iron overload)	X	X	X	X	
Describe the role of parametric imaging in the differential diagnosis of infiltrative cardiomyopathies	X	X	X	X	
List common non-ischemic conditions that can present with a dilated cardiomyopathy phenotype	X	X	X	X	
Describe the CMR findings that provide prognostic information for DCM patients		X	X	X	
Recognize the general CMR features of drug toxicity affecting the heart, including but not limited to oncology drugs (e.g. cancer therapy related cardiac dysfunction)		X	X	X	
Describe typical CMR features of arrhythmogenic cardiomyopathy and its diagnostic criteria[17,18]	X	X	X	X	
Recognize atypical presentations of arrhythmogenic cardiomyopathy such as biventricular disease or pure LV involvement		X	X	X	
Describe the typical findings of myocarditis and be familiar with the diagnostic criteria for myocardial inflammation (revised Lake Louise Criteria)[19]	X	X	X	X	
Describe the features of emerging causes of myocardial inflammation such as COVID-19/COVID vaccine myocarditis and Immune-checkpoint-inhibitor related myocarditis[20,21]		X	X	X	
Describe the imaging features of stress-induced cardiomyopathy (Tako-Tsubo cardiomyopathy)	X	X	X	X	
Recognize the CMR features of eosinophilic syndromes such as Hypereosinophilic syndrome and eosinophilic granulomatosis with polyangiitis (EGPA)		X	X	X	
Recognize the CMR features of peripartum cardiomyopathy		X	X	X	
Recognize the CMR features of autoimmune diseases with myocardial involvement, including connective tissue diseases and vasculitides		X	X	X	

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Table 2 (*continued*)

Learning Objectives	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Recognize the CMR features of cardiac sarcoidosis, including features that provide prognostic information	X	X	X	X	
Demonstrate the ability to communicate CMR findings clearly to guide patient management and follow up	X	X	X	X	
Contribute to multidisciplinary inherited cardiac disease conferences	X	X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Pericardium & Tumor and Masses:					
Recognize common conditions affecting the pericardium such as acute pericarditis, pericardial effusion and hemopericardium, pericardial calcification and constrictive physiology	X	X	X	X	
List the optimal MR sequences used to diagnose constrictive physiology and their strengths and limitations		X	X	X	
Describe the typical CMR appearance of common cardiac masses from thrombi to tumors	X	X	X	X	
List the common imaging sequences that help characterize cardiac masses and determine resectability and understand their strengths and limitations	X	X	X		
List imaging features that can help differentiate benign from malignant cardiac masses	X	X	X	X	
Describe how emerging techniques such as parametric mapping can be useful for tumor evaluation		X			
Demonstrate the ability to communicate complex CMR findings clearly and give appropriate advice on management and follow up	X	X	X	X	
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Vascular (aorta and coronary vasculitis)					
Describe normal aorta anatomy ● Diameter ● Aortic arch normal branching pattern and variants ● Abdominal aortic branches ● Aorta terminal branches (pelvic outflow)	X	X	X	X	
Describe MR sequences used for aorta evaluation ● Spin echo ● Gradient echo (steady state free precession and phase contrast flow imaging) ● 3D-angiography (contrast enhances and 3D-SSFP)	X	X	X	X	
Demonstrate knowledge of identifying aortic pathology ● Aortic aneurysm (size, location, etiology: congenital vs acquired) ● Aortic dissection (typical vs atypical: location, extension, complications) ● Penetrating ulcer (location) ● Aortitis (location; extension) ● Post-aortic surgery: expected and un-expected findings (dehiscence, rupture, endograft leaks ● Post-traumatic aortic transection (location, extension)	X	X	X	X	
Demonstrate knowledge of identifying coronary artery course and origin	X	X	X	X	
Demonstrate knowledge of identifying coronary artery vasculitis	X	X	X	X	
Describe MR sequences that can identify the proximal coronary arteries	X	X	X	X	
Demonstrate the ability to communicate vascular anatomy and physiology details	X	X	X	X	
Contribute to multidisciplinary vascular conferences	X	X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Valvular Disease					
Describe the normal anatomy and function of cardiac valves and the appearance on CMR	X	X	X	X	
List the most common cardiovascular lesions that are associated with valvular heart diseases	X	X	X	X	

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Table 2 (*continued*)

Learning Objectives	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
List the utility of different CMR sequences for the evaluation of valvular anatomy, dynamic assessment of function and quantification of stenosis/regurgitation severity, including their strengths and limitations	X	X		X	
Explain the complementary role of CMR, echocardiography and CT for the assessment of valvular heart disease, and know where CMR adds value	X	X		X	
Describe the methods to acquire the image planes for accurate flow quantification for each one of the cardiac valves	X	X		X	
Describe the optimal parameter settings for flow sequence optimization and strategies to reduce artifacts	X	X		X	
Recognize the abnormal appearance of leaflet coaptation and excursion, and acceleration and regurgitant jets on cine imaging	X	X		X	
Describe the cardiac adaptations seen with valvular stenosis and regurgitation, including changes in volumes, wall thickness and function	X	X	X	X	
Recognize abnormal myocardial tissue characteristics that can be seen in valvular heart disease (e.g., amyloidosis, fibrosis)	X	X	X	X	
Describe the post processing methods used for volumetric and flow quantification using commercially available software	X	X		X	
Describe the standard methods of quantifying valvular regurgitant fraction using flow and volumetric CMR data	X	X		X	
Recognize the CMR appearance of the most common post-operative complications of valve replacement		X		X	
Describe advanced CMR techniques for valve assessment such as valve tracking and 4D flow		X		X	
List the sequences and quantification methods for CMR planning for transarterial valve replacement for the pulmonary, aortic and mitral valves		X		X	
Demonstrate the ability to communicate findings clearly in the context of other imaging in particular echocardiography	X	X	X	X	
Contribute to multidisciplinary valvular heart disease conferences	X	X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Congenital Heart Disease:					
Describe the anatomy and physiology of common congenital heart disease lesions	X	X	X	X	
Recognize normal anatomic variants	X	X	X	X	
Describe an approach to segmental anatomy and morphologic characteristics in congenital heart disease patients		X	X	X	
Describe the surgical procedures used to repair common congenital heart lesions and their complications or anticipated sequelae		X	X	X	
Apply of knowledge to help guide interventions in congenital heart disease patients		X	X	X	
Recognize the various etiologies of right heart enlargement	X	X	X	X	
Describe the various methods to calculate shunt fraction (Qp/Qs)		X	X	X	
Describe methods to calculate valvular regurgitant fraction, recognizing their technical limitations and pitfalls	X	X	X	X	
Describe the unique aspects to quantification of ventricular size and function in congenital heart disease patients		X	X	X	
Recognize the importance of indexing the size of ventricular chambers and great vessels to body size	X	X	X	X	
Demonstrate the ability to communicate congenital anatomy and physiology details		X	X	X	
Attend multidisciplinary congenital heart disease conference		X	X	X	X
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Extra-Cardiac Findings (Common Findings and Management):					
Recognize the limitation of CMR to confidently characterize incidental extra-cardiac findings and know when to recommend further imaging when necessary.	X	X	X	X	
Demonstrate knowledge of identifying normal neck anatomy and common pathology such as thyroid nodules and lymph nodes	X	X	X	X	X

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Table 2 (*continued*)

Learning Objectives	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Demonstrate knowledge of identifying normal thoracic anatomy and common pathology:	X	X	X	X	X
• Lung (e.g. mass)					
• Pleura (e.g. effusion or thickening)					
• Mediastinum (e.g. lymph nodes, mass)					
• Osseous structures (e.g. mass)					
• Chest wall (e.g mass)					
Demonstrate knowledge of identifying upper abdomen anatomy and common pathology	X	X	X	X	X
• Liver (e.g. cyst and mass)					
• Spleen (e.g. cyst and mass)					
• Kidney (e.g. cyst, mass, hydronephrosis)					
• Adrenals (e.g. mass)					
• Gallbladder (e.g. stones, mass)					
• Other (e.g. lymph nodes, ascites)					
	Level II Independent Practitioner (IP)	Level III Advanced Practitioner (AP)	Medical Knowledge	Patient Care	Systems-Based Practice
Management skills					
Understand key aspects of CMR reimbursement		X	X	X	X
Demonstrate knowledge of quality assessment methods		X	X	X	X
Demonstrate ability to lead a multi-disciplinary CMR team		X	X	X	X
Be aware of current appropriateness criteria for CMR versus other modalities	X	X	X	X	X

medical physics and the clinical context of CMR, 'Patient Care', which represents all aspects of how CMR impacts the management of patients, and 'Systems-Based Practice', which stands for CMR in the larger context and system of health care, and effective resource use to provide optimal health care.

3. Approach to training schemes

3.1. Current training schemes for CMR

Various frameworks of core competencies exist worldwide. For instance, in the United States of America (USA), the Accreditation Council for Graduate Medical Education (ACGME) has established 6 core competencies that make up the cornerstone trainee education and evaluation:

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
6) professionalism

In the UK and Europe, systems like Capabilities in Practice (CiPs) or Entrustable Professional Activities (EPAs) have been developed and are being used in the Core Cardiology Curriculum of the European Society of Cardiology (ESC) [22]. These systems focus on the characterization of the tasks a practitioner can be trusted to perform. The European Society of Radiology (ESR) approaches the training curriculum in three scopes: Knowledge, skills, and competencies/attitudes, which is very similar to the ACGME approach [23,24]. In Canada, the CanMEDS competencies offer a framework for competency-based curricula incorporating the domains of medical expert, collaborator, leader, health advocate, scholar, and professionalism [25,26]. Many other national and regional approaches exist, and despite differences in structure and outline, the core knowledge and skills that are required for advanced training in CMR share many common components between the different approaches.

This SCMR document uses the framework of the ACGME core competencies, and the concept of CiPs/EPAs, to create a document with global validity for the education and assessment of trainees across these core competencies, allowing them to be fully qualified to supervise, evaluate and interpret CMR.

3.2. Educating CMR trainees from different training backgrounds

CMR trainees typically emerge from two principal training environments: radiology and cardiology, including pediatric cardiology, with inherent differences in the scope of acquired skills and competencies in their overall training programs.

Worldwide, there are differences in the nomenclature of training programs and precise description of competencies involved. Nevertheless, there is often a similar structure starting with a period of general training in cardiology or radiology followed by a subsequent period of specialized training. A dedicated high-quality CMR training program needs to accommodate for these differences, eventually ensuring an appropriate competency/capability level and expertise in interpreting CMR examinations.

For both Level II and Level III CMR competency, multimodality cardiac training is desirable for both radiologists and cardiologists. Radiology training curricula are by definition multimodality and include cardiovascular CT and MR as formal and integral parts of the curriculum. However, advanced training is usually offered as a cardiothoracic fellowship, combined with pulmonary imaging, or a cardiovascular fellowship, combined with peripheral vascular imaging. In cardiology, most training programs that include CMR also offer echocardiography and frequently CT or Nuclear Medicine training. More recently, comprehensive multimodality imaging fellowships have emerged that are designed for cardiology trainees interested in a primary imaging career including comprehensive training in these 4 imaging modalities. Multimodality training in both radiology and cardiology further provides opportunities to fully understand the strengths and limitations of different cardiac imaging modalities, and provide valuable assistance in selecting the best imaging method according to the clinical problem at hand [27].

In addition to the requirements for Level II training, Level III skills and competencies in CMR could be achieved by a dedicated CMR imaging fellowship. However the training could also be part of a multimodality training program or can be achieved during a dedicated CMR research program. Such cardiac imaging Level III programs are usually offered in large centers with high case volumes and case diversity to support broad trainee education. In a center with high case volumes, training to achieve Level III typically lasts 12 months, but can vary according to case volumes and local expertise to achieve the competency-based learning outcomes. However, some of the advanced expertise certification programs require 2 additional years of dedicated training in CMR to achieve advanced certification.

3.3. Accommodating variations in case volume and case diversity

The evaluation of training adequacy should be based on competency (or capability) rather than focusing solely on attaining specific CMR case numbers. While total training time and case number targets help standardize training experience and minimum required exposure to enable the achievement of competency, the reality is more nuanced, with several factors warranting consideration.

Firstly, case numbers often represent the minimum case volume necessary to achieve competency, without accounting for the varying rates at which trainees individually progress during different stages of learning.

Additionally, case diversity is often regional, because local pathology and the spectrum of diseases encountered by cardiac imagers may vary significantly from center to center. Training at centers with lower caseloads or without direct access to Level III cardiac imager guidance may require longer training periods or supplementation of attended/scanned cases with additional training material or educational sessions.

Furthermore, supervision and mentoring by Level III cardiac imagers and service providers knowledgeable in prevalent local diseases, as well as access to trainers during scanning sessions, will differ among centers. This variability should be considered when planning local training programs and is especially relevant in areas with a low density of accredited CMR imagers. The COVID-19 pandemic has facilitated virtual online learning and meeting platforms that can also be used for didactic teaching, assistance with protocol development and selection, support for image acquisition, analysis and interpretation [15] for those wishing to learn more CMR in the absence of local expertise. However, this cannot completely replace the need for hands-on training in clinical practice.

Lastly, as outlined in the core competencies tables, the breadth and depth of knowledge and experience required for Level II and III will differ. Consequently, exposure to and knowledge of less frequently encountered pathologies may be expected for demonstrating competency in the Level III group, which may be more difficult to acquire depending on the training center.

These factors should be considered when planning competency assessments. Rigid standardized evaluation of logbooks over-emphasizes logged case numbers and may not reflect these nuances. Reporting and discussing selected archived cases to supplement case diversity, attending CMR courses, or participating in training events at other centers or promoted by imaging societies such as the SCMR may help increase the necessary exposure to achieve training milestones.

3.4. Proposed training schemes for CMR level III (AP, advanced practitioner)

Any Level III training curriculum should emphasize more complex applications of CMR and analysis of complex cardiac diseases. A broader focus on integrating into a multidisciplinary team and leveraging the advanced skills of both cardiology and radiology is expected of a Level III practitioner.

A comprehensive Level III curriculum should involve direct mentorship by the laboratory director or other supervisors so that education in the business and administrative aspects of leading a CMR lab are incorporated. This could include involvement with new equipment purchases, personnel management, protocol development, and performance improvement (PI)/quality assessment (QA) programs. Irrespective of the method of healthcare funding (private or public), knowledge of the local systems and methods of reimbursement is key to a successful CMR program, particularly with the constantly changing landscape of medical reimbursement and payer structures.

A strong foundation in appropriateness criteria and quality assurance is also vital to a future laboratory director or program director and should be incorporated into Level III level training. These elements include, but are not limited to, checking indications, evaluating whether another modality may be more efficient for the specific clinical problem, technical planning of the examination (including protocol development and image optimization), training and supervision of MR technologists, post-processing of the obtained data, reporting of the findings, MR safety issues, and ensuring long-term storage and accessibility of CMR images and post-processed data.

Understanding that a critical revision and potential restructure of a CMR training curriculum can be time consuming, this document seeks to facilitate the process for program directors. The ACGME core competencies listed in Table 2 allow for program directors to more easily develop trainee evaluations to ensure learners are meeting specific learning milestones. It also allows for identification of knowledge gaps earlier in the training process, when they can more easily be addressed.

4. Potential challenges in developing a CMR training program

4.1. Variations in national and regional healthcare policies

This curriculum document aims to set international standards of CMR training and education. It is recognized that there are significant variations in healthcare policies across different countries, with important differences in the requirements for medical specialists to perform CMR, access to MR equipment and billing rights for MR examinations; however, discussion and proposed solutions for specific practice challenges related to local policy are beyond the scope of this document. This document aims at providing guidance in developing CMR training programs that are widely applicable. Collaborations between radiology and cardiology programs are desired for these training programs, and possibilities for common paths for collaboration are further discussed in Section 5.

4.2. Congenital heart disease and adult congenital heart disease

CMR is an important imaging modality for diagnosis and surveillance of various congenital heart defects due to its ability to provide 3-dimensional evaluation of anatomy and to comprehensively assess valve and ventricular function. Several societies have released guidance documents detailing the indications, assessment, and usage of CMR for this particular group of patients [28,29]. However, obtaining the necessary skills and competency in congenital heart disease (CHD) and adult congenital heart disease (ACHD) can be difficult in practice. CMR expertise in CHD/ACHD may require a dedicated training period in a specialist center to achieve the skills and competencies required for independent interpretation of such cases.

Although ability to perform and report complex CHD studies is not required for adult CMR Level II practitioner, a core knowledge of basic CMR principles in the assessment of these patients should be expected along with the ability to recognize basic abnormalities that can then be referred on for more specialist evaluation, if required [29]. This knowledge will allow practitioners to conduct an initial assessment and identify abnormalities that may prompt patient referral to advanced sub-specialized evaluation [29]. For Level III practitioners, knowledge in CMR preparation, monitoring and interpretation for pediatric and adult CHD is highly desirable.

In addition, the level of expertise needed for longer-term work as a Level III imager may depend on the local needs, as frequently pediatric and advanced ACHD care is delivered in dedicated hospitals and healthcare centers. This limits the (continued) exposure of Level III imagers to CHD, unless working in an experienced CHD center; it also questions the need for in-depth expertise in CHD, dependent on the work environment.

Competency of Level II and III cardiac imagers in CHD should be assessed in areas of preparation, performance, and interpretation of CMR cases. Ideally, cases should be reviewed with an experienced CMR faculty with expertise in CHD. Trainees may also be encouraged to present CHD cases at multidisciplinary conferences and maintain an electronic log of all congenital studies performed and interpreted. Where there is lack of local expertise in CHD, seeking consultation with other experts in the same region, attending courses (either in-person or online) or taking mini-fellowships may be a feasible alternative to acquire, interpret and analyze CMR in CHD cases.

5. Collaboration between cardiology and radiology

Program directors and training programs should emphasize the positive synergy between cardiologists and radiologists working together in the field of CMR whenever possible, both locally in departments and nationally and internationally, to lobby for improved access and appropriate utilization of CMR. Many successful CMR programs have cardiac imagers from both radiology and cardiology as independent or advanced practitioners and working together in a collaborative and collegial environment. This offers an ideal environment for trainees to see both specialty perspectives and to benefit from the strengths of both training backgrounds [30]. This also represents the current reality of the wider CMR community, with strong collaborative practice between cardiology and radiology emphasized at major national and international meetings.

Such a positive synergistic approach then readily identifies the ways in which a high quality comprehensive CMR training program would need adaptation (please see section below). Fig. 1 outlines common CMR training pathways for both cardiology and radiology trainees. However, this is only by way of example and is neither exhaustive nor exclusive with many other factors such as case mix and local expertise being important in the development of such a program. Given local variations in case volume, diversity, and supervisor expertise, the training duration may vary.

Collaboration between radiology and cardiology in a training program can take different shapes, including weekly CMR case discussions, multidisciplinary team attendance, etc. Another example is elective rotations, where radiology and cardiology trainees can spend a period of training at the other department. It is important that trainees can be exposed to both cardiology and radiology perspectives and to learn from the strengths of both specialties. Ideally, CMR training programs should include faculty from cardiology and radiology, whenever possible, so that the training includes the experience of working as a team, contributing to a better understanding of complex cases and together improving patient care [30].

6. Identification and possible solutions to differences in training backgrounds

This competency-based training curriculum should serve as a foundational framework for designing a local program, considering the unique combination of factors including participants from different training backgrounds, individual variations in expertise, and the range of previous exposure to clinical cases before entering the training program. The final goal is to produce competent Level II and III CMR imagers.

Achieving this goal involves accounting for the differences between the background expertise of cardiology and radiology trainees when they enter CMR training, and adaptation of the educational program to the needs of the learners. Given their mainly clinical training, cardiology trainees are more likely to require supplemental training in MR physics, protocol optimization, and extra-cardiac anatomy and pathology. Technical proficiency gaps can be addressed by incorporating supervised hands-on scanner training experience, involving technologists, radiologists, medical physicists, and experienced CMR practitioners. The SCMR educational platform provides additional extensive material to supplement these training aspects. Most training programs consider this a mandatory part of their curriculum.

Conversely, radiology trainees, having a more extensive technical and broad cardiothoracic imaging background, may benefit from additional educational content focused on cardiac pathophysiology, echocardiography, parameters defining clinical outcomes, and treatment guidelines focusing on the management of cardiovascular disease. Such training can ideally be provided by cardiology departments, at clinical multi-disciplinary team meetings and attendance of cardiology conferences. In addition, the SCMR educational platform and SCMR documents are other useful sources of information on the use of CMR in different clinical scenarios.

Joint reading sessions between cardiology and radiology trainees and faculty/consultants can further help bridge any gaps in knowledge and skill, and reinforce the collaboration and synergy between radiology and cardiology disciplines. In addition, joint or double reading

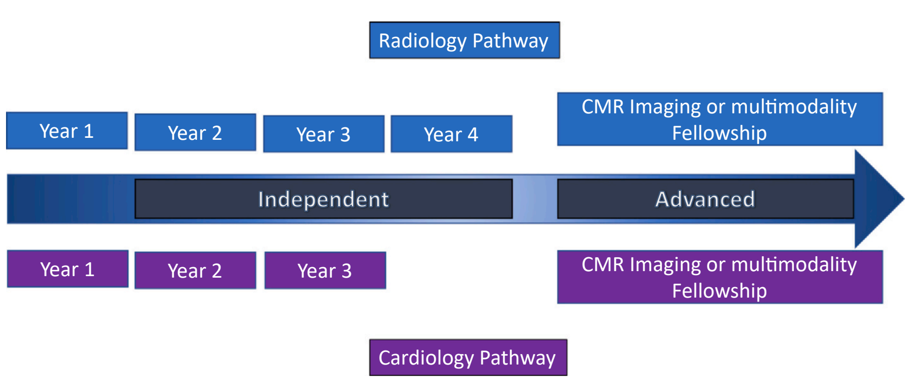

Fig. 1. Competency-based pathways to Level II and III CMR training.

of CMR cases can optimize the reporting of incidental non-cardiac findings, and the interpretation of cardiovascular findings in the clinical context. Joint reading sessions involving cardiology and radiology can also facilitate review of prior relevant multimodality imaging (echocardiograms, CT and invasive angiography etc.) to obtain a more comprehensive and contextualized understanding of a CMR study.

A team-based approach to the hands-on scanner training experience, which could involve technologists, medical physicists/engineers, and the laboratory director, increases the level of understanding and depth of knowledge. Hands-on experience for scanning and image acquisition for both Levels II and III attainment is very helpful to balance out gaps in training and should be highly encouraged. Furthermore, the exposure to multiple CMR manufacturers and thereby different scanner platforms and interfaces should be encouraged for Level III to facilitate a deeper understanding of the strengths and limitations among different vendor platforms. For both Level II and III, discussion and presentation of findings at multidisciplinary clinical case conferences offer rich learning experience by facilitating development of valuable presentation and interpretive skills.

7. Didactic curriculum and other learning resources

While a large proportion of the Level II and III training curriculum can be administered in conjunction with live case review, a full didactic curriculum is vital to supplement where gaps in training supervision or case diversity exist. A didactic curriculum could incorporate lectures from local experts which may be complemented with webinars, societal educational offerings, and attendance at annual scientific meetings. Online training, webinars and simulation environments may be a useful learning adjunct in lower volume or smaller programs to supplement experience in less common CMR applications. A list of educational resources is provided in the Supplementary section.

7.1. Certification and verification of training

Certification is a process whereby a trainee, who has completed the required training, can request a letter of certification or verification from national bodies or international imaging societies such as the SCMR.

The SCMR currently issues letters of verification (formerly called "letters of certification") for Level I, II and III. According to SCMR guidelines first published in 2000 and updated in 2007 and 2018 [14,31], only trainees who have specifically completed the SCMR educational requirements are eligible to receive letters of verification of their training. Other imaging societies such as the North American Society of Cardiovascular Imaging (NASCI) also offer letters of verification of CMR training in collaboration with the American College of Radiology (ACR) and Society for Pediatric Radiology (SPR). In the US, a Certification Board in Cardiovascular Magnetic Resonance (CBCMR) has been implemented in 2019 as a mechanism for certification of competency to independently perform CMR. For radiologists, the American Board of Radiology provides board certification after radiologists have passed both a core exam on general radiology and a radiology subspecialty exam, the credentialling exam, that is usually performed during or after fellowship. In Europe, both the European Association of Cardiovascular Imaging (EACVI) and the European Society of Cardiovascular Radiology (ESCR) offer a certifying exam to document expertise in CMR. Such European examinations are optional in most countries but may be required at some institutions for credentialing purposes.

All program directors in charge of training programs must evaluate competency of their trainees during and at the end of the training period to ensure that they have achieved the required knowledge and skills to practice competently and independently. This is often done when reviewing cases with trainees and by careful review of their CMR imaging reports, assessment of their ability to assign an appropriate protocol and monitor cases at the scanner etc. In-training examinations may be a useful adjunct to evaluation of competency of trainees through standardized tests [27]. Ultimately, successful completion of dedicated CMR imaging training programs that follow the recommendations of this competency document could serve as proof of adequate training, especially in countries where mechanisms for certification on CMR are lacking.

8. Summary

The rapid growth and expansion of CMR requires training programs to adopt a comprehensive training curriculum to meet the growing need for Level II and III cardiac imagers with basic and advanced understanding of all aspects of CMR. As new technologies continue to emerge with sufficient evidence for efficacy and meaningful impact on clinical management, it is expected that the training recommendations will evolve. The core elements of this document are expected to remain foundational for Levels II and III competency, while future updates to this training curriculum will be forthcoming as new evidence emerges that guide best practice in CMR.

This competency-based curriculum intends to add value to the 2018 SCMR Curriculum Guidelines [14], which was mostly based on case volume. We encourage adoption of this curriculum to promote a training experience that reflects a standardized level of competence for both cardiology and radiology trainees pursuing basic and advanced training in CMR. The ultimate goal of this document is to promote the development of a competent radiology and cardiology CMR workforce to meet the needs of a rapidly expanding field.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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