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TECHNICAL NOTES

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Society for cardiovascular magnetic resonance recommendations for training and competency of CMR technologists

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Abstract

The Society for Cardiovascular Magnetic Resonance (SCMR) recommendations for training and competency of cardiovascular magnetic resonance (CMR) technologists document will define the knowledge, experiences and skills required for a technologist to be competent in CMR imaging. By providing a framework for CMR training and competency the overarching goal is to promote the performance of high-quality CMR and to foster the increased adoption of CMR into clinical care.

Background

The combination of a rapid pace of imaging innovation and clinical data has positioned cardiovascular magnetic resonance (CMR) as a vital imaging modality in the evaluation and management of a wide range of cardiovascular diseases. In particular, CMR is widely regarded as the optimal imaging modality for the assessment of biventricular volumes, regional and global systolic function, myocardial viability, stress perfusion imaging, dilated and infiltrative cardiomyopathy, and congenital heart disease (CHD). However, despite its expanding and important role in cardiovascular care it is widely acknowledged that there are significant regional variations in CMR service delivery. For instance, in 2017 there were more CMR studies performed in London, United Kingdom than in the entire United States Medicare population [1]. The inequities in access to CMR imaging can be linked to multiple challenges in the initiation and development of a CMR program. Competent and well-trained CMR technologists are fundamental to the success of a CMR program, and the current limited availability of CMR technologists is a challenge for CMR adoption more widely into clinical care.

Guidelines and/or formal education in CMR imaging for magnetic resonance (MR) technologists are neither widely available nor standardized worldwide. In the United States, MR technologists are typically educated in a 2-year Associate Degree program that includes MR physics, MR safety, instrumentation, patient care procedures, MR quality control and the performance of MR procedures. Notably, education and training in CMR is not required and often not included as an elective in MR technologist training programs. In fact, the American Registry of Radiologic Technologists (AART) the world's largest organization offering credentials in MR and other medical imaging) does not recognize CMR as a separate MR procedure [2]. The ARRT requires demonstrated competence in 17 mandatory MR procedures and at least 11 of 30 elective MR procedures. CMR is not included as either a mandatory or elective MR procedure. Consequently, training in CMR is not a requirement to be a candidate for MR certification, nor is CMR

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content present in the ARRT certifying examination. In the United Kingdom, the standards of proficiency for radiographers from the Health and Care Professions Council does not have any requirements for content regarding CMR training [3].

Achieving proficiency in CMR imaging is time-intensive, requiring mastery of the application and adjustments of numerous cardiovascular pulse sequences and protocols. There are no shortcuts-CMR training is rigorous with a large time requirement needed to become an independent CMR technologist capable of consistently performing high quality CMR scans. Education in cardiovascular anatomy, physiology, pathology, and clinical indications for cardiac imaging is inherently necessary to achieve proficiency in CMR imaging, and are not a novel concept in technologist training. For example, an advanced level of cardiovascular education has been a long-standing component of the training of cardiac sonographers [4–6]. Furthermore, technologists receiving suboptimal CMR training can adversely impact patient care through the performance of low-quality, incomplete and longer duration CMR studies. The absence of formal CMR technologist training guidelines are a significant barrier to the successful implementation and expansion of CMR in clinical practice, and is problematic in several ways: (1) Without training standards, the pathway for technologists to achieve CMR proficiency is nebulous. (2) Determining the quality and/or comprehensive nature of a CMR training program without established guidelines is difficult for aspiring CMR technologists. Establishing CMR guidelines should foster the incorporation of education and training in CMR into MR technologist programs, facilitate the verification of technologist training and instigate pathways for healthcare systems to establish CMR technologist positions.

Despite the importance of the CMR technologist and the expanding role of CMR in cardiovascular care, there are no guideline recommendations for MR technologist training and competency in CMR. In recognition of the complex nature of CMR imaging and accelerating clinical demand for CMR, the Society for Cardiovascular Magnetic Resonance (SCMR) considers it a priority to provide guidelines for training and competency in CMR for MR technologists. A goal in establishing these guidelines is to address the limitations that exist for CMR technologist training and competency in order to facilitate the penetrance of CMR into clinical care. The SCMR has developed these guidelines to be broad-based in view of the marked heterogeneity of CMR centers worldwide. The objective of this report is to provide guidelines and competency milestones for MR technologists training in CMR. This document has been reviewed and approved by the SCMR Executive Committee.

Recommendations for technologist training in CMR

This document defines the knowledge, experiences and skills required for a technologist to be competent in CMR imaging. By providing a framework for CMR training and competency the overarching goal is to promote the performance of high-quality CMR and to foster the increased adoption of CMR into clinical care.

The classification of knowledge and skills will be assigned into basic (Level 1), intermediate (Level 2), and advanced (Level 3) levels to mirror the categorization of CMR physician skill levels [7]. Complex CHD CMR, pediatric CMR, CMR under anesthesia and CMR post-processing are assigned to an additional Specialty CMR category. Estimates of the duration of training and number of CMR exams performed to achieve competency in the different levels is provided. The writing committee acknowledges that the time required to achieve proficiency in CMR imaging will vary reflective of diverse CMR practice settings, patient volumes and differing rates of skill acquisition amongst learners. As such, the number of cases performed and achievement of domain milestones is the determinant of a CMR technologist skill level rather than the cumulative training time needed to reach a skill level. The training and competency milestones for each skill level will be categorized into five domains: Patient safety/preparation, indications for CMR, electrocardiogram (ECG) gating, CMR scanning and CMR protocols [8].

The CMR technologist should achieve proficiency in each of the domains for a given skill level. The writing committee further acknowledges that the scope of clinical studies provided by CMR programs is varied. Therefore, the expectation is that a technologist demonstrate competency in at least 2/3 of the CMR protocols for each skill level. It should be emphasized that the CMR technologists must be capable of competently performing an extensive range of clinical CMR exams in order to meet Level 2 training requirements. Furthermore, technologists can perform Level 3 protocols even if they do not have the requisite training and/or experience to be a Level 3 CMR technologist. MR technologists who have completed Level 3 training will be qualified to serve in a supervisory and teaching role for a CMR program. The training supervision provided by a Level 2 or higher technologist or physician is to ensure that the training is consistent with site-specific protocols and the SCMR recommended protocols.

Importantly, the recommendations in this document should not be viewed or interpreted rigidly, as they are intended to guide the assessment of competency of a CMR technologist (Figs. 1, 2).

Training and competency milestone domains	Classification of Skill (COS)	
[1] Patient safety/preparation [2] Indications for CMR scan [3] ECG gating [4] CMR scanning [5] CMR protocols	Level 1 - Basic	Introductory knowledge and skills in CMR that should be part of the training for all MR technologists
	Level 2 - Intermediate	Specialized training for a technologist to independently perform CMR studies
	Level 3 - Advanced	Advanced training for CMR technologists that will perform in a supervisory and teaching role for a CMR program
	Specialty CMR	Specialty training in complex congenital CMR, pediatric CMR and CMR under anesthesia, CMR image post-processing

Fig. 1 Classification of skill levels. *CMR* cardiovascular magnetic resonance, *ECG* electrocardiogram, *MR* magnetic resonance

Skill Level		Recommended minimum number of cases	Approximate time to achieve a skill level*
Level 1		30 cases	4 weeks
Level 2		150 cases	4 months
Level 3		300 cases	6 months
Specialty CMR	Complex Congenital	50 cases	2-4 months
	Pediatric CMR	30 cases	2-6 weeks
	Anesthesia	10 cases	1-4 weeks
	Post-processing	20 cases	2-4 weeks

*Actual time required to achieve a given skill level will depend on the number of cases performed at the CMR facility.

Fig. 2 Minimum number of cases and expected time needed for each skill level. Note that only cases performed as the CMR operator should be counted towards competency

Level 1 skills

These are the CMR foundational skills for a CMR technologist. Level 1 assumes general competency in the operation of a CMR scanner, as well as a prior degree or certification in MR. Level 1 competency encompasses a knowledge of the indications for the most common CMR procedures, and fluency in the technical considerations for acquiring cardiac images. This CMR training should be conducted under the supervision of a Level 2 or Level 3 (preferred) physician and/or technologist. A technologist with Level 1 skills can be expected to independently perform a basic exam for cardiac volumes and function. While a non-contrast CMR exam is limited in scope, it provides the technologist with the fundamental image acquisition skills and begins to familiarize the technologist with normal and abnormal cardiac findings. It is recommended that initial training should consist of observing at least 10 CMR studies. After the observation period, a minimum of 30 CMR exams is needed to acquire Level 1 CMR skills. Only cases performed as the primary scanner operator should be counted towards this competency. Although the length of time needed to achieve Level 1 skills may vary by center CMR volume, in general, it should take 4 weeks total (observation of 10 cases followed by the performance of 30 CMR exams) (Fig. 3).

Level 2 skills

These skills encompass the requirements needed to perform CMR for the majority of clinical indications and build on the foundational Level 1 skills. Similar to Level 1, this CMR training should be conducted under the

COS	Recommendation
	Patient Safety/Preparation
Level 1	Demonstrate knowledge of general MR safety, metal screening, contraindications for CMR
	Indication for scan
Level 1	Knowledge of appropriate indication for non-contrast CMR evaluation of cardiac morphology and function
	ECG gating
Level 1	Proficiency in applying the different types of ECG gating (retrospective, prospective, real-time) appropriate to the cardiac rhythm and cycle length Place ECG electrodes and troubleshoot ECG signal problems Recognize and understand the different common cardiac rhythms including atrial fibrillation, PVCs, PACs.
	Protocols
Level 1	Assessment of LV function
	Scanning
Level 1	*Overall* Mastery of breath-hold instructions *Protocol Specific Skills* ***LV function and morphology*** Set up standard cardiac views (short-axis, 4Ch, 3Ch, 2Ch) Identify major cardiac anatomy: the left and right ventricles, left and right atria, all cardiac valves, thoracic aorta, pulmonary artery, vena cava and pulmonary veins Acquire bSSFP short axis images from base of LV through the apex

Fig. 3 Level 1 skills. *2Ch* two-chamber, *3Ch* three-chamber, *4Ch* four-chamber, *bSSFP* balanced steady state free precession, *LV* left ventricle/left ventricular, *PACs* premature atrial contractions, *PVCs* premature ventricular contractions

supervision of a Level 2 or Level 3 (preferred) physician and/or technologist.

A CMR technologist with Level 2 skills can be expected to perform post-contrast examinations, including myocardial viability, assessment of heart failure and infiltrative cardiomyopathies, hypertrophic cardiomyopathy, myocarditis, arrhythmogenic cardiomyopathy, pericardial disease and assessment of cardiac masses. As this level of competency is significantly broader than Level 1, it is recommended that performing at least 150 CMR exams is needed to acquire Level 2 CMR skills. Although the length of time needed to achieve Level 2 skills may vary by center CMR volume, 4 months of CMR imaging is recommended (Fig. 4).

Level 3 skills

The skills that encompass Level 3 training are for CMR centers that perform less common, advanced CMR studies including assessment of valvular heart disease, basic CHD, CMR scanning of device patients, vasodilator stress perfusion imaging and advanced magnetic resonance angiography (MRA) techniques. This CMR training should be conducted under the supervision of a Level 3 physician and/or technologist. As these CMR scans are inherently more complex, the CMR technologist will need a more advanced knowledge of cardiac anatomy and physiology, in addition to possessing a solid understanding of the interplay of different CMR sequence parameters that govern temporal and spatial resolution, SNR, and scan duration. The CMR technologist with Level 3 skills should be able to adjust or change the scan protocol based on cardiac findings observed during the CMR exam. The Level 3 technologist should be able to provide preliminary findings of the CMR exam to the attending physician. It is recommended that at least 300 CMR exams are needed to acquire Level 3 CMR skills. Although the length of time needed to achieve Level 3 skills may vary by center CMR volume, 6 months of CMR imaging is recommended (Fig. 5).

Specialty CMR

Specialty CMR refers to procedures that are not routinely performed at many CMR centers. These include centers that perform examinations for complex CHD, pediatric CMR imaging, CMR scanning under anesthesia and CMR post-processing. In addition to all the Level 2

COS	Recommendation
Level 1	All of the Level 1 recommendations
	Patient Safety/Preparation
Level 2	Demonstrates knowledge of the principles guiding safe gadolinium administration for CMR
	Indication for scan
Level 2	Demonstrates knowledge of the common cardiac issues for which patients undergo CMR with contrast studies
	ECG gating
Level 2	Can troubleshoot arrythmias and make appropriate sequence adjustments for: •Atrial fibrillation/flutter •Tachycardia •Bradycardia •Frequent ectopy Recognize and resolve imaging artifacts from improper ECG-gating Make appropriate heart rate specific adjustments to imaging parameters to maintain adequate temporal resolution for cine and LGE imaging Adjust segments or gating factor for patients with bradycardia or tachycardia during LGE imaging
	Protocols
Level 2	Evaluation of myocardial viability prior to coronary revascularization Assessment of iron overload (thalassemia) Cardiomyopathy/heart failure protocol HCM protocol including evaluation of LV outflow tract obstruction/systolic anterior motion of the mitral valve ARVC protocol including the two orthogonal RV outflow tract views, RV 2-chamber view Cardiac amyloidosis protocol Cardiac sarcoidosis protocol Myocarditis protocol Cancer-related cardiomyopathy protocol Post-heart transplantation protocol ECG-gated thoracic aorta MRA protocol Pulmonary vein evaluation (pre and post-ablation) protocol Pericardial disease protocol including acute pericarditis and evaluation for constrictive pericarditis Cardiac mass protocol
	Scanning
Level 2	*Overall* Provides appropriate weight-based contrast doses Consistently encourage and coach a patient to comply with the instructions needed for a high-quality CMR exam Recognizes when a patient is having difficulties that necessitates pausing the CMR exam and taking the patient out of the bore to evaluate Employs parallel imaging techniques to reduce scan and breath-hold times *Artifact Reduction and Identification* Can differentiate artifacts due to poor breath-holding vs ECG-gating during cine imaging Employ strategies to minimize banding artifact during bSSFP imaging Patient specific shimming and frequency adjustments *Protocol Specific Skills* ***General*** Acquire axial set of single-shot bSSFP or black blood images through the chest Perform T1 and T2 spin echo imaging Acquire RV specific views (RV 2 chamber, RV outflow tract) ***Iron Overload (e.g. Thalassemia)*** Acquire gradient echo images for T2* analysis ***Myocardial Viability*** Employ appropriate sequences for myocardial viability Set the TI correctly (null normal myocardium) for LGE imaging Recognize and resolve artifacts on LGE imaging through phase swapping and FOV adjustments Set the TI to null thrombus for thrombus assessment using LGE ***Velocity Encoded Imaging*** Correctly set the VENC parameter for velocity encoded imaging ***CE-MRA*** Acquire an ECG-gated MRA of the pulmonary veins Properly use CMR-compatible power injector for contrast-enhanced MRA Optimize acquisition timing for contrast-enhanced MRA using bolus tracking or test bolus techniques Acquire an ECG-gated thoracic MRA Perform navigator-gated 3D, free-breathing, SSFP imaging ***Parametric Mapping*** Perform native T1 and post-contrast T1 mapping Perform T2 mapping

Fig. 4 Level 2 skills. *ARVC* arrhythmic right ventricular cardiomyopathy, *HCM* hypertrophic cardiomyopathy, *LGE* late gadolinium enhancement, *MRA* magnetic resonance angiography, *RV* right ventricle/right ventricular, *TI* inversion time, *VENC* velocity encoding

COS	Recommendation
Level 2	All of the Level 2 recommendations
	Patient Safety/Preparation
Level 3	Knows contraindications to adenosine/regadenoson/dipyridamole stress CMR Screens patient for caffeine prior to vasodilator stress CMR
	Indication for scan
Level 3	Understanding of basic congenital heart disease (aortic coarctation, bicuspid aortic valve, ASD/VSD, repaired tetralogy of Fallot, PDA) Knowledge of the common cardiac issues that would prompt a CMR stress exam
	ECG gating
Level 3	Technologist can troubleshoot heart rate response during stress imaging
	Protocols
Level 3	Valve regurgitation and stenosis protocols Peripheral MRA protocol Basic congenital heart disease protocols: aorta coarctation, ASD/VSD, sinus venosus defect, repaired tetralogy of Fallot, PDA Stress perfusion CMR protocol
	Scanning
Level 3	*Overall* Adjust or change scan protocol based on cardiac findings observed during CMR exam Educate, train, and supervise beginning, Level 1 and Level 2 technologists *Protocol Specific Skills* ***Valve disease assessment*** Acquire en-face views of all cardiac valves Acquire flow-velocity images in non-traditional locations (e.g. in-plane flow of the aortic arch to assess for coarctation) ***Implanted cardiac devices*** Employ appropriate acquisition adjustments to overcome image artifacts generated by the device Pulse sequence modifications to improve image quality ***Stress Perfusion*** Set up appropriate short axis slices for stress perfusion imaging Make appropriate adjustments to stress perfusion protocols (no phase oversampling etc) Perform optimal breath-hold instructions during stress perfusion imaging Properly use CMR-compatible power injector for myocardial perfusion imaging

Fig. 5 Level 3 skills. *ASD* atrial septal defect, *PDAi* patent ductus arteriosus, *VSD* ventricular septal defect

and Level 3 CMR requirements, it is recommended that the technologist has performed the following number of scans: Complex CHD-50 exams, Pediatric CMR-30 exams, CMR scanning under anesthesia-10 exams, CMR post-processing-20 exams (Fig. 6).

Continuing education and maintenance of competence

CMR is experiencing a rapid pace of pulse sequence and cardiac protocol evolution mandating that CMR technologists performing CMR exams be engaged in efforts to maintain their CMR skills. As part of the continuing education (CE) credits required to maintain technologist accreditation and/or foster knowledge of CMR advancements, a technologist should ensure that $\geq 25\%$ of those CE credits are related to CMR for those at skill Level 1 and $\geq 50\%$ for higher skill levels.

Performance of at least 100 CMR exams every 2 years is required for maintenance of Level 2 competence. Performance of at least 200 CMR exams every 2 years is required for maintenance of Level 3 competence.

It is also recommended that CMR technologists at or higher than Level 2 attend a local, regional, national or international meeting that includes CMR content every 1–2 years. Attendance (in person or virtual) at CMR focused meetings will foster education in a didactic format, encourage networking amongst CMR technologists, and provide access to cutting edge research and technical developments.

COS	Recommendation
Level 3	All of the Level 3 recommendations
	Advanced indications for scan
Specialty CMR	**Complex congenital heart disease:** Transposition of the great arteries, single ventricle, tricuspid atresia, double outlet right ventricle • Knowledge of the anatomic and functional abnormalities associated with each type • Knowledge of the surgical repairs for complex congenital heart diseases including Fontan repair, Mustard/Senning procedure, Rastelli procedure, RV-PA conduits **CMR scanning under anesthesia** • General understanding of how to coordinate acquisition of breath-holds with ventilation cessation • Modifying acquisitions for free breathing (for example: use multiple averages) • Safety of anesthesia equipment in the CMR environment, need to monitor anesthesia support personnel for CMR safety **Pediatric scanning** • Coaching of young patients to complete exam and perform breath-holds • MR screening of parents planning to remain in the scan room with the patient • How to adapt sequences to free breathing protocols, elevated heart rates **Post-processing** • Perform the left and right ventricular volume and ejection fraction (LVEF, RVEF) analysis • LV Mass • T2* image analysis and determination the T2* of the myocardium • T1 and T2 mapping, ECV calculation • General flow analysis • Flow analysis of valvular heart disease (e.g. regurgitant fraction) and shunts (e.g. Qp/Qs) • PV ostial measurements • Aortic measurements at the American Heart Association recommended locations

Fig. 6 Specialty CMR skills. *ECV* extracellular volume fraction, *LVEF* left ventricular ejection fraction, *Qp/Qs* pulmonary to systemic flow ratio, *PA* pulmonary artery, *RVEF* right ventricular ejection fraction

Abbreviations
ARRT: American Registry of Radiologic Technologists; CE: Continuing education; CHD: Congenital heart disease; CMR: Cardiovascular magnetic resonance; ECG: Electrocardiogram; MR: Magnetic resonance; MRA: Magnetic resonance angiography; SCMR: Society for Cardiovascular Magnetic Resonance.

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