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Task Force 12: Training in Advanced Cardiovascular Imaging (Cardiovascular Magnetic Resonance [CMR])

Endorsed by the Society for Cardiovascular Magnetic Resonance

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Cardiovascular magnetic resonance (CMR) (Table 1), one of the newest cardiovascular imaging modalities, provides useful, often unique information with which all cardiologists should be conversant. Training in CMR for cardiology fellows should be divided into three levels.

TRAINING LEVELS

Level 1—General training (1 month) to provide the cardiovascular trainee with a working knowledge of CMR methods and diagnostic utility.

Level 2—Specialized training (at least 3 months) designed to provide fellows with the skills necessary to independently interpret CMR imaging studies.

Level 3—Advanced training for those who ultimately wish to be responsible for the operation of a CMR laboratory. Level 3 criteria must include appropriate levels of patient care, teaching, and research.

OVERVIEW OF CMR TRAINING

All cardiovascular medicine trainees should be taught the basic types of CMR studies and their indications. Mentored interpretation of CMR studies should be coupled with comparison and integration of test results with other relevant clinical and laboratory data. A mentor is an individual with the equivalent of Level 3 CMR training. This training generally should be acquired through the Accreditation Council for Graduate Medical Education—an approved cardiology or radiology program with expertise in CMR and under the aegis of a Level 3-qualified mentor in a laboratory accredited by an organization such as the Intersocietal Commission on the Accreditation of MR Laboratories (ICAMRL). Occasionally, a Level 3 qualified mentor will not be available in the institution housing the general fellowship program, but is available at a nearby non-academic but medical center accredited for CMR by an organization such as the ICAMRL. Under these circumstances it is acceptable to place the trainee(s) at such a medical center for Level 1 to Level 3 training. The CMR training center and the trainee should maintain a logbook or other specific records to document the trainee's case review and the didactic hours in which the trainee has participated.

The depth of knowledge should increase with increasing levels of training. In the case of the Level 3 trainee, specialized training and, for academic trainees, research should be offered as a part of an established training program (Table 2).

LEVEL 1: GENERAL TRAINING (1-MONTH MINIMUM)

The trainee should have exposure to the methods and the multiple applications of CMR for a period of not less than 1 month or its equivalent when interwoven with other training activities. This experience should provide basic background knowledge in CMR sufficient for the practice of adult cardiology and referral for CMR, but not for the practice/independent clinical interpretation of CMR. As a practical matter, many fellowship programs in cardiovascular medicine may not be able to fulfill CMR training. In these instances, fellows should be encouraged to obtain experience in an alternate program with appropriate training and accreditation in the performance of CMR studies.

Didactic Activities

Interpretation of CMR studies. During their 1-month of training, trainees should actively participate in daily CMR study interpretation under the direction of a Level 2- or Level 3-trained CMR physician-mentor. For all studies in which angiographic, echocardiographic, radionuclide, computed tomography, or hemodynamic data are available, such information should be correlated with CMR studies. Studies should include the range of procedures listed in Table 1. Experience in interpretation (a minimum of 50 cases) may include studies from an established CMR teaching file.

Lectures and self-study in CMR. This component should consist of lectures on the basic aspects of CMR and parallel reading material of selected articles, digital training programs, or CMR text. The lectures and reading should provide the fellow with an understanding of CMR applications. Specificity, sensitivity, diagnostic accuracy, utility in assessing prognosis and use of interventions, costs, artifacts, indications, contraindications, and pitfalls must be included for each cardiovascular diagnostic subset. Such information could be effectively transmitted within a weekly non-invasive or clinical teaching conference during which CMR data are presented.

A basic understanding of magnetic resonance physics should be provided, including the following: 1) the physics of magnetic resonance as it relates to image intensity and contrast, including flow, T_1 (spin-lattice relaxation time),

Table 1. Classification of CMR Procedures

1. Standard CMR procedures, including:
   a. Tomographic still-frame CMR for morphology using "bright" and/or "dark blood" methods with and/or without a paramagnetic contrast agent
   b. Cine and other approaches to CMR for assessment of ventricular function
   c. Magnetic resonance angiography and cine CMR of the great vessels, anomalous coronary arteries, and coronary artery bypass grafts
   d. Delayed contrast-enhanced CMR imaging for myocardial infarction, scar, intraventricular thrombus and microvascular obstruction (associated with MI) and viability assessment and visualization of other causes of abnormal myocardial interstitium
   e. First-pass CMR imaging (with vasodilator infusion) or cine CMR imaging with stress (with inotropic agent) for myocardial perfusion evaluation and ischemia detection
   f. Phase-contrast velocity mapping for blood flow quantification for shunt sizing and determination of regurgitation and stenosis
   g. Peripheral MR angiography
2. Less common procedures, including:
   a. Myocardial tagging (approach unique to CMR that allows more detailed evaluation of intramural and transmural myocardial function than ventriculography alone and for evaluation of pericardial disease)
   b. MR angiography of the native coronary arteries
   c. MR spectroscopy using ^{31}P (to assess "high-energy phosphate metabolism") or other nuclei

CMR = cardiovascular magnetic resonance; MI = myocardial infarction; MR = magnetic resonance.

T_2 (spin-spin relaxation time) and contrast agents; 2) sources of artifacts, including motion, arrhythmias, and metal objects; contrast agent side effects; 3) safety of devices in the CMR environment; and 4) general post-processing tools and analyses.

Hands-On Experience

Hands-on experience is not necessary for Level 1.

LEVEL 2: SPECIALIZED TRAINING (AT LEAST 3 MONTHS)

Training for Level 2 should begin with the CMR experience outlined in Level 1. Level 2 is for those trainees who wish to practice the specialty of CMR, including independent interpretation of CMR studies. Level 2 trainees must have at least 3 months of dedicated CMR training (where 1 month is defined as 4 weeks and a week is defined as 35 h), including the basic elements listed in the following text. The trainee would be expected to become familiar with the CMR techniques listed in Table 1.

Background

In addition to Level 1 training, understanding of CMR physics should be more advanced (see the following text).

Didactic Activities

Interpretation of CMR studies. During their 3 or more months of experience, trainees should actively participate in daily CMR study interpretation under the direction of a Level 2 or Level 3 (preferred) CMR-qualified physician. For all studies in which other cardiac imaging data are available, such information should be correlated with CMR data. The trainee should interpret at least 150 CMR examinations during this training period, including 50 for which the trainee is present during the scan, ideally as the primary operator and is the primary interpreter. Up to 50 of the 100 examinations for which the trainee is not the primary interpreter can be derived from established teaching files, journals, and/or textbooks or electronic/on-line courses. Careful documentation of all case material and the details of the way in which the case was derived is essential.

Lectures and self-study in CMR. Course work would include the components for Level 1 training but also should include more advanced lectures and reading materials. This work, with parallel reading, should continue for the duration of the traineeship. Course work should include the following:

1. Physics: trainees should receive didactic lectures from a CMR-trained physician and/or physicist on the basic physics of magnetic resonance in general and CMR in particular. The content should include the same materials as in Level 1 (basic) plus lectures with supportive reading on the following topics:
   a. Image formation, including k-space, gradient echo, spin echo, fast spin echo, echo planar, spiral, steady-state free precession (SSFP), and parallel imaging.
   b. Specialized imaging sequences, including flow and motion, phase imaging, time of flight, contrast agents, and radiofrequency tagging.
   c. Hardware components, including the elements of gradient coil design, receiver coils, and digital sampling.
2. Applications, interpretation, indications, and contraindications: Level 2 didactic activities should include an understanding of the sensitivity, specificity, accuracy, utility, costs, acquisition approaches, and disadvantages of all of the contemporary techniques in CMR. The following techniques should be covered in the didactic program:
   a. Imaging of structure and tissue characterization (T1, T2, spin echo, gradient echo, SSFP, and fat suppression).

Table 2. Components of CMR Training

1. Didactic activities
   a. Lectures (it will be necessary in learning the physical principles and in case interpretation to derive such information from relevant lectures–no more than 5% of the cases)
   b. Self-study (it is possible to use cases from teaching files, journals, textbooks, or electronic/on-line courses. Such self-study cases need to be well documented in the trainee's records and should not comprise any more than 50% of the cases studied)
2. Independent interpretation of CMR cases (performed in the mentoring CMR laboratory)
3. Participation in CMR case study interpretation
4. "Hands-on" CMR experience

CMR = cardiovascular magnetic resonance.

b. Imaging of function (cine and tagged cine magnetic resonance including SSFP imaging).
c. Volumetric imaging of mass, biventricular volumes, and ejection fraction (using cine magnetic resonance imaging).
d. Flow imaging (e.g., velocity-encoded techniques).
e. Imaging of myocardial infarction, scarring, and viability assessment (delayed contrast-enhancement imaging).
f. Pharmacologic stress-testing with evaluation of ventricular function and/or first-pass perfusion using a contrast agent.
g. Magnetic resonance angiography (vascular).
h. Electrocardiogram and peripheral pulse gating and triggering including timing of image acquisition within the R-R interval, motion artifacts and their effects on CMR images; respiratory motion suppression methods (e.g., breath-holding and navigators).
i. Magnetic resonance spectroscopy methods (e.g., depth resolved surface coil spectroscopy or DRESS).
j. Cardiovascular magnetic resonance image analysis and post-processing tools.
k. Contraindications for CMR study.
l. Incidental findings suggesting pathology outside of the cardiovascular system.

Evaluation

The person responsible for the CMR training program must be responsible for assessing the competence of the CMR trainee at the completion of the program. This is accomplished by examining the ability of the trainee in the understanding of the acquisition methods and the interactive role of the operator during the performance of studies and in the interpretation of the data acquired during daily reading sessions. This may be supplemented by formal testing.

LEVEL 3: ADVANCED TRAINING (12 MONTHS OR MORE FOR THOSE INTERESTED IN RUNNING AN ACADEMIC PROGRAM)

Level 3 CMR training represents the highest level of training and would enable the trainee to pursue a clinical or academic career in CMR and to direct a CMR laboratory. Level 3 training in CMR could be obtained as part of a 3- or 4-year cardiology fellowship. In addition to the recommendation for Level 2, the Level 3/academic program should include active participation in ongoing basic or clinical CMR research or both, with individual responsibility for a specific portion of that research. Focused research work with publication of one or more manuscripts is an important part of Level 3 training. Level 3 training must be performed under the guidance of at least one Level 3-trained CMR physician.

In parallel with research activities, the Level 3 trainee must participate in clinical imaging that should include supervised interpretation of at least 300 CMR cases. The trainee must be physically present and involved in the acquisition and the primary interpretation of at least 100 CMR cases. In the remaining 200 cases, the trainee should review at least 100 of these with the Level 3 mentor at the training facility. The remaining cases can be derived from established teaching files, journals, and/or textbooks or electronic/on-line courses. Careful documentation of all case material and the details of the way in which the case was derived are essential.

Table 3. Summary of Requirements for Each Level of CMR Training

Level	Duration of Training (Months)	Number of Cases
1	1	50+ Mentored interpretations (by a Level 2- or 3-trained physician)
2	3 to 6*	150+ Mentored interpretations (by a certified Level 2- or Level 3-[preferred] qualified CMR physician) including at least 50 as primary interpreter (and operator, if possible)†
3	12 or more months of training*	300+ Mentored interpretations (by a Level 3-qualified CMR physician) including 100+ as primary interpreter (and operator, if possible)†

*This time represents the number of months spent reviewing cases, and interpreting, performing, and learning about CMR, and need not be a consecutive block of time, but at least 50% of the time should represent mentored laboratory experience. †The case recommendations may include studies from an established teaching file, previous CMR cases, journals, and/or textbook or electronic/on-line courses/continuing medical education. No less than 50% of the cases should be from those performed at the mentoring CMR laboratory.
CMR = cardiovascular magnetic resonance.

Knowledge of magnetic resonance physics must be more advanced than Level 2 and include the following:

1. Analysis of why certain specialized imaging sequences are applicable for specific clinical protocols, including imaging of heart function, coronary arteries, perfusion, delayed enhancement, and peripheral arteries.
2. Basic understanding of the clinically applicable spectroscopic methods.
3. The essentials of data collection, including capturing of digital data, the maintenance of accurate databases and records, signal processing, and the approach for obtaining quantitative data.

Evaluation

Evaluation should be similar to that of Level 2.

Summary of Recommendations

The overall requirements for training in CMR are summarized in Table 3.

This is an update of the 2002 document that was written by Gerald M. Pohost, MD, FACC, Raymond J. Kim, MD, FACC, Christopher M. Kramer, MD, FACC, and Nathaniel Reichek, MD, FACC.

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APPENDIX 1. Author Relationships With Industry for the ACCF 2006 Update for Training in Adult Cardiovascular Medicine—Task Force 12: Advanced Cardiovascular Imaging (Cardiovascular Magnetic Resonance)

Name	Consultant	Research Grant	Scientific Advisory Board	Speakers' Bureau	Steering Committee	Stock Holder	Other
Dr. Raymond J. Kim	Mallinckrodt	None	None	None	None	None	Siemens-Educational Grant
Dr. Christopher M. Kramer	None	Fujisawa Novartis	None	GE Healthcare	None	None	Siemens, Merck-Research materials support
Dr. Warren J. Manning	None	None	None	None	None	None	None
Dr. Gerald M. Pohost	None	None	None	Takeda Pharmaceuticals	None	None	None

This table represents the relationships of committee members with industry that were reported by the authors as relevant to this topic. It does not necessarily reflect relationships with industry at the time of publication.

APPENDIX 2. External Peer Reviewer Relationships With Industry for the ACCF 2006 Update for Training in Adult Cardiovascular Medicine-Task Force 12: Training in Advanced Cardiovascular Imaging (Cardiac Magnetic Resonance)*

Peer Reviewer Name†	Representation	Consultant	Research Grant	Scientific Advisory Board	Speakers' Bureau	Stock Holder
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Dr. John McB. Hodgson	Organizational Reviewer–Society for Cardiovascular Angiography and Interventions	Volcano	GE Medical	GE Medical	Volcano	Technology Solutions Group
Dr. Spencer King, III	Content Reviewer–ACCF Cardiac Catheterization and Intervention Committee	None	None	None	None	None
Dr. Edward T. Martin	Content Reviewer–Individual Review	Guidant	Guidant	Guidant	GE Medical	None
Dr. Patrick O'Gara	ACC Official Reviewer–Board of Trustees	Boston Scientific Corp.	None	None	None	None
Dr. Dudley Pennell	Content Reviewer–Individual Review	Siemens BMS Novartis	None	Preventicum	None	Cardiovascular Imaging Solutions
Dr. Nathaniel Reichek	Content Reviewer–Individual Review	None	None	None	None	None

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Peer Reviewer Name†	Representation	Consultant	Research Grant	Scientific Advisory Board	Speakers' Bureau	Stock Holder
Dr. Charanjit S. Rihal	Content Reviewer–ACCF Cardiac Catheterization and Intervention Committee	None	None	None	None	None
Dr. Thomas L. Rosamond	ACC Official Reviewer–Board of Governors	None	None	None	None	None
Dr. Carlos Ruiz	Content Reviewer–ACCF Cardiac Catheterization and Intervention Committee	None	None	None	None	None
Dr. Robert Schwartz	Organizational Reviewer–Society of Cardiovascular Angiography & Intervention	None	None	None	None	None

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