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COMPETENCE AND TRAINING STATEMENT

ACCF 2008 Training Statement on Multimodality Noninvasive Cardiovascular Imaging

A Report of the American College of Cardiology Foundation/American Heart Association/ American College of Physicians Task Force on Clinical Competence and Training

Developed in Collaboration With the American Society of Echocardiography, the American Society of Nuclear Cardiology, the Society of Cardiovascular Computed Tomography, the Society for Cardiovascular Magnetic Resonance, and the Society for Vascular Medicine

Writing Committee Members

James D. Thomas, MD, FACC, *Co-Chair*
William A. Zoghbi, MD, FACC, *Co-Chair*

George A. Beller, MD, MACC
Robert O. Bonow, MD, MACC
Matthew J. Budoff, MD, FACC
Manuel D. Cerqueira, MD, FACC
Mark A. Creager, MD, FACC*
Pamela S. Douglas, MD, MACC
Valentin Fuster, MD, PhD, FACC
Mario J. Garcia, MD, FACC†
David R. Holmes, Jr, MD, FACC
Warren J. Manning, MD, FACC‡
Gerald M. Pohost, MD, FACC
Thomas J. Ryan, MD, FACC
William A. Van Decker, MD, FACC§
Susan E. Wiegers, MD, FACC‖

*SVM Representative; †SCCT Representative; ‡SCMR Representative; §ASNC Representative; ‖ASE Representative

Task Force Members

Jonathan L. Halperin, MD, FACC, FAHA, *Chair*
Mark A. Creager, MD, FACC, FAHA, *Past Chair*¶

Gordon L. Fung, MD, PhD, FACC, FAHA, FACP
David R. Holmes, Jr, MD, FACC, FAHA, FACP
Geno Merli, MD, FACP
Ira S. Nash, MD, FACC, FAHA, FACP
L. Kristin Newby, MD, MHS, FACC, FAHA
Ileana Piña, MD, FACC, FAHA, FACP
Howard H. Weitz, MD, FACC, FACP

¶Former Task Force member during the writing effort

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Preamble

The American College of Cardiology Foundation (ACCF)/ American Heart Association (AHA)/American College of Physicians (ACP) Task Force on Clinical Competence and Training was formed to develop recommendations for attaining and maintaining the cognitive and technical skills necessary for the competent performance of a specific cardiovascular service, procedure, or technology. The ACCF Recommendations for Training in Adult Cardiovascular Medicine Core Cardiology Training document (referred to as COCATS, based on the original Core Cardiology Training Symposium held in June 1994) comes under the auspices of this task force. The 2008 version of COCATS comprises 13 task force reports pertaining to training in cardiovascular medicine (1). It includes training recommendations for 4 distinct imaging modalities: nuclear cardiology, echocardiography, cardiovascular magnetic resonance (CMR), and cardiovascular computed tomography (CCT). An additional imaging technique described as part of vascular medicine training is vascular ultrasound. The current paradigm of training requires fellows to learn about the unique characteristics of each imaging modality separately. Yet, there are important areas of knowledge and training that overlap cardiovascular imaging modalities. An integrated approach to fellowship training in cardiovascular imaging offers unique advantages for assimilation of knowledge in basic science, physics, image acquisition and processing, clinical indications, performance, and interpretation of findings, as well as learning a patient-centered, rather than technology-focused, approach to imaging. Moreover, recognizing that the time required for training in cardiovascular medicine is ever increasing, it is appropriate to consider training formats that are efficient, yet without sacrificing acquisition of knowledge or skills. Accordingly, in order to streamline the core training of fellows and also allow for advanced training in the area of cardiovascular imaging, the ACCF established a Multimodality Imaging (MMI) Training Writing Committee composed of broad-based imaging specialists. The MMI Training Writing Committee consisted of representatives from the ACCF including the chairs of COCATS and its task forces on training in nuclear cardiology, echocardiography, CMR, CCT, and vascular medicine, as well as representatives from the American Society of Echocardiography (ASE), the American Society of Nuclear Cardiology (ASNC), the Society of Cardiovascular Computed Tomography (SCCT), the Society for Cardiovascular Magnetic Resonance (SCMR), and the Society for Vascular Medicine (SVM). This ACCF Training Statement on Multimodality Noninvasive Cardiovascular Imaging should be considered a supplement and update to COCATS (1).

The ACCF/AHA/ACP Task Force makes every effort to minimize actual or potential conflicts of interest that might arise as a result of an outside relationship or a personal interest of a member of the MMI Writing Committee. Specifically, all members of the writing committee are asked to provide disclosure statements of external relationships that might be perceived as real or potential conflicts of interest relevant to the document topic. These are reviewed by the writing committee and updated as changes occur. The relationships with industry information for authors and peer reviewers are published in the appendixes of the document. Membership on the writing committee has been constituted to balance expertise in the individual imaging modalities while representing the needs of general cardiologists for accurate and efficient clinical diagnosis.

Jonathan L. Halperin, MD, FACC, FAHA
Chair, ACCF/AHA/ACP Task Force on
Clinical Competence and Training

I. Introduction

Training in cardiovascular disease must evolve in response to diagnostic and therapeutic advances. In particular, the field of cardiovascular imaging has shown dramatic progress in the past decade. Whereas training in imaging in the past primarily consisted of separate didactic and practical instruction in echocardiography and nuclear cardiology, it is recognized that contemporary graduates of cardiovascular fellowships should have exposure to and training in the new modalities of CMR and CCT. Further, since imaging is best performed in a patient-centric manner, it is critical that training also cross technological boundaries.

As part of the COCATS process, the ACCF, in collaboration with imaging subspecialty societies, has developed training documents aimed to define requirements for training to various levels of expertise in each of the major imaging modalities (1). The Writing Committee took care to maintain consistency between the recommendations in this document and those in COCATS, and when differences were appropriate, the reasons are explicitly stated. Because advances in cardiovascular imaging involve not only technological developments but the applications to an increasing number of vascular regions and disease states, it is not possible to maintain perfect harmony among documents developed for various purposes. Accordingly, despite efforts to avoid disparities between this document, COCATS, and other ACCF statements, when inconsistencies appear the reader should generally employ those most recently published. With the added scope of new imaging modalities, it is more difficult to accommodate comprehensive training in imaging in the conventional 3-year fellowship program without affecting other facets of fellowship training. For example, obtaining the highest level of expertise (Level 3) in all 4 modalities under the existing COCATS requirements would require at least 42 months of dedicated training, leaving no time for other requisite cardiology training topics. The task of the ACCF Writing Committee on Multimodality Noninvasive Cardiovascular Imaging is to provide the guidance for training in cardiovascular imaging essential to providing cardiovascular health services and to identify efficiencies that occur when these modalities are learned as part of an integrated MMI program, either within a categorical cardiology training program or in a dedicated advanced imaging fellowship.

This document will first briefly review the specific modalities under consideration and general issues about levels of expertise in training. A presentation of requirements for training in general cardiovascular imaging will follow, including requisite background knowledge, basic science and safety curricula, and applications in common to multiple modalities. Training issues in specific modalities will then be discussed briefly, without attempting to supplant existing COCATS documents in these modalities. These training requirements will then be integrated into proposals for instruction within the 3-year categorical cardiovascular fellowship as well as advanced training in MMI. Finally, these issues will be considered with respect to potential board certification in cardiovascular imaging.

II. Noninvasive Cardiovascular Imaging Modalities

Noninvasive cardiovascular imaging has evolved significantly over the years and has become an essential approach in clinical practice, spanning prevention to diagnosis to management of cardiovascular disease. Whereas traditionally these imaging modalities consisted predominantly of ultrasound and radionuclide techniques, recent advances in technology have made computed tomography (CT) and magnetic resonance imaging valuable tools in the diagnosis of cardiovascular disease that complement the more established modalities.

Echocardiography and vascular ultrasound use the principle of ultrasound emanating from a hand-held transducer to interrogate cardiovascular structures in multiple tomographic planes and more recently in real-time 3-dimensional views. A transesophageal approach complements surface imaging, enhancing visualization of posterior structures, certain valvular conditions, and the aorta. Advances in technology have made ultrasound devices more compact, easily utilized at the bedside, in the intensive care unit, or in the clinic. With echocardiography, information about cardiac structure, systolic and diastolic function, valvular heart disease, and cardiac synchrony can be gleaned in real time. Doppler interrogation allows assessment of blood and tissue velocity for cardiac hemodynamic and functional assessment. The technique is versatile and is used in combination with stress testing for the diagnosis of ischemic heart disease. Vascular ultrasonography integrates B-mode imaging with pulsed Doppler and is used to evaluate peripheral arteries for the presence of occlusive and aneurysmal diseases and veins for thrombosis, stenosis, and insufficiency. Three-dimensional techniques allow detailed analysis of cardiovascular anatomy.

Radionuclide techniques use radionuclide tracers for evaluation of cardiac function and ischemic heart disease. Radionuclide cameras detect photons emitted from the tracer that are either taken up by the myocardium or retained in the blood pool to evaluate global and regional myocardial perfusion and function. Most frequently, radionuclide techniques are used in combination with stress testing for the evaluation of comparative regional myocardial blood flow at rest and during stress for the detection of flow-limiting coronary artery disease (CAD). Global and regional ventricular function is also quantified. Currently, most laboratories use single-photon emission tomography (SPECT) as opposed to planar imaging. Positron emission tomography (PET) provides a unique quantitative assessment of myocardial blood flow and coronary flow reserve in addition to myocardial metabolism and glucose uptake, and is particularly useful in evaluation of myocardial viability and ischemic heart disease. Hybrid SPECT/CT and PET/CT systems are being used with increasing frequency. Molecular imaging can assist in early detection of disease and tracking stem cell efficacy.

Cardiovascular magnetic resonance uses magnetic fields and radio waves to excite the protons (hydrogen nuclei) in the body and to generate images of cardiac and vascular structures. Sequential tomographic imaging of the heart and surrounding structures are obtained, and images allow quantitation of cardiac size, global and regional function, assessment of valvular abnormalities, coronary anatomy, myocardial viability, and diseases of the aorta, great vessels, and peripheral vessels. Injection of gadolinium-based CMR contrast agents can define vascular anatomy and delineate areas of myocardial fibrosis that are used in the assessment of myocardial viability and cardiomyopathies. Pharmacologic stress testing can be used with CMR for the detection of ischemic heart disease and contractile reserve. Flow can be quantified in the great vessels.

Cardiovascular computed tomography uses X-ray–based cross-sectional imaging with high temporal and spatial resolution to image cardiovascular structures, including the coronary arteries. Noncontrast-enhanced imaging with a relatively low radiation exposure can be used to detect and quantify calcifications in the coronary arteries, which are an early marker of CAD, applicable in the context of risk stratification. After contrast injection, multidetector CT systems allow imaging of cardiac morphology and function, including visualization of coronary arterial lumen and plaque as well as imaging of peripheral vessels.

With the above imaging modalities, a comprehensive assessment of cardiovascular structure and function can be obtained to help the clinician in pre-clinical diagnosis and prevention, in providing an accurate diagnosis in symptomatic patients, and in managing the cardiac condition. The various imaging modalities may have overlapping capabilities, particularly in the areas of cardiac structure, ischemic heart disease, and cardiac function. Knowledge of the specifics of image acquisition, safety issues, advantages, limitations, and clinical applications is crucial for an appropriate, cost-effective utilization of these modalities.

III. Levels of Training in Noninvasive Cardiovascular Imaging

Cardiovascular imaging is an evolving family of technologies experiencing continued improvement, with an expanding list of clinical indications. Three levels of expertise are defined for training in cardiovascular imaging:

Level 1—Basic training required of all trainees to be competent consultant cardiologists. This level makes trainees conversant with all imaging modalities along with their clinical utility. It provides superficial exposure to performance and interpretation of all modalities.

Level 2—Additional training that enables the cardiologist to interpret cardiovascular imaging studies independently.

Level 3—Advanced training that enables a cardiologist to perform, interpret, and train others to perform and interpret specific imaging studies at the highest skill level. This is the expertise expected for directors of imaging laboratories.

All cardiologists must attain at least Level 1 training in every cardiovascular imaging modality. This entails understanding the basic principles, indications, applications, technical advantages, and limitations of each imaging modality, and their interrelationship with other diagnostic methods. Level 1 training may also include interpretation of studies under supervision and, for some modalities (echocardiography or nuclear cardiology), performance of a number of studies (1). For modalities not requiring actual performance of studies to achieve Level 1 training (vascular ultrasound, CCT, CMR), the number of cases required can be garnered by exposure in courses, case studies, CD/DVD training, attendance at major medical meetings devoted to performance of these modalities, or other relevant educational training activities, particularly if exposure to the imaging modality is not available at the training institution. Trainees at Level 2 and 3 are required to perform and interpret an incremental number of studies in each imaging modality (1). Trainees at all levels should integrate their understanding of 3-dimensional cardiac anatomy, physiology, and pathophysiology and correlate imaging findings with the history and physical examination, results of other tests, and patient management. Only those fellows who go beyond the basic Level 1 and attain Level 2 or 3 training in each modality are trained sufficiently for independent interpretation of imaging studies in that modality. In all cases, the training center and the trainee should maintain a logbook or other specific records to document the cases performed and/or interpreted and the didactic hours in which the trainee has participated. Specific requirements for optimal training for the 3 levels differ across modalities, have been recently addressed separately in COCATS, and are detailed collectively later in this document.

Table 1. Training Requirements for Noninvasive Cardiovascular Imaging: Single and Multimodality Training

Area	Level	Cumulative Duration (in Months) of Traditional Single Modality Training*	Cumulative Duration (in Months) of Multimodality Training: Total/Unshared Minimum/Maximum Shared With 1 Other Modality†	Minimal Cumulative Number of Cases: Performed/Interpreted	Comments
Ultrasound					
Echocardiography	1	3	3/2/1	75/150 cases	TEE—50 cases and Stress—100 cases
	2	6	6/4/2	150/300 cases	
	3	12	12/6/6	300/750 cases	
Vascular	1	0.5‡	0.5/0/0.5	0/50 cases	
	Advanced§		3/2/1	375 vascular cases	
Nuclear cardiology	1	2	2/1/1	35/100 cases	Radiation safety: 80 h of didactics and laboratory and 620 h in the clinical environment
	2	4 to 6	4/3/1	35/300 cases	
	3	12	10/5/5	35/600 cases	
CMR					
Cardiac MR	1	1‖	1/0/1	0/25 cases	.
	2	3 to 6	3/2/1	50/150 cases	
	3	12	10/5/5	100/300 cases	
Vascular MR	2	Cases only	Part of Levels 2 to 3 CMR	50/150 vascular cases	
CCT					
Cardiac CT	1	1‖	1/0/1	0/50 cases	
	2	2	2/1/1	50/150 cases	
	3	6	6/3/3	100/300 cases	
Vascular CT	2	Cases only	Part of Levels 2 to 3 CCT	50/150 vascular cases	

Explanation: In the fourth column, the duration of training for each modality shows 3 numbers for each level of training in an a/b/c format, where "a" refers to the total number of months needed for training in that modality (typically matching the current COCATS requirements), "b" is the number of months that must be spent *exclusively* in that modality (in particular, mastering image acquisition and patient safety), and "c" is the number of months that can be shared between the modality in question and another modality. In all cases, the total number of months needed for a modality is equal to the dedicated months and those shared between modalities (a = b + c). *When all training is performed in separate imaging rotations; †training may involve simultaneous rotations of no more than 2 modalities at a time (e.g., Echo and Nuclear; Nuclear and CCT; Echo and CMR); ‡can be taken concurrently with clinical or imaging rotations; §Levels 2 and 3 for vascular ultrasound not defined in COCATS; ‖can be taken as part of 7 months of noninvasive imaging rotation.

CCT = cardiovascular computed tomography; CMR = cardiovascular magnetic resonance; CT = computed tomography; MR = magnetic resonance; TEE = transesophageal echocardiography.

To attain Level 1 training, the trainee should be exposed to the fundamentals of imaging during core clinical training (ranging from 0.5 to 3 months for the various modalities as summarized in Table 1). This experience provides overall familiarity with imaging technology and its clinical applications in the general clinical practice of adult cardiology, but it is not sufficient for the specific practice of any imaging technique. The components of training include a didactic program consisting of lectures, web-based cases, self-study, and clinical exposure.

The second level of training in imaging (Level 2) should provide the knowledge and experience necessary to perform and interpret cardiovascular imaging studies in that modality independently, under the supervision of the laboratory director or another Level 3-trained physician. As the practice of cardiovascular medicine is currently quite dependent on imaging, all general cardiovascular trainees are encouraged to attain Level 2 training in at least 1 modality and preferably in 2. Details of the competencies and case volume required for each modality are discussed below and summarized in Table 1. Some fellows may choose to attain Level 2 training in more than 2 modalities and/or Level 3 in 1 or more modalities. This will require additional months depending on the number of modalities; the complexity of each; specific characteristics of each program including local availability, intensity of training, and laboratory case volumes; and the feasibility of training simultaneously in 2 modalities. The specified exposure to and training in each modality include mastering additional didactic material as well as imaging performance and interpretation as described later in this report.

Attaining Level 3 expertise in a specific modality enables the trainee to gain additional expertise in various special procedures particular to the modality and to be eligible to direct an imaging laboratory. Training to achieve Level 3 expertise must include involvement in patient care, teaching, and research. In general, working with a Level 3-qualified mentor in a laboratory accredited by an organization such as the Intersocietal Accreditation Commission is required to reach this level. However, since these may not be available for all modalities in the institution housing the general fellowship program, they may be obtained in another institution, ideally one that is fully accredited by the Accreditation Council for Graduate Medical Education (ACGME), but at a minimum one that possesses the necessary expertise and credentialing noted above.

IV. General Requirements for Training

A. Background Knowledge

It is assumed that incoming fellows to a cardiology training program arrive with certain background knowledge in mathematics, physics, anatomy, pathology, and physiology. This section is not meant to provide a comprehensive curriculum for background knowledge in imaging, but will merely highlight areas that fellows should ideally be familiar with as they enter into a cardiology training program and in particular, the imaging section of that program. Whereas some fellows are more readily familiar with cardiovascular anatomy, pathology, and physiology, and mathematical and physics principles required for imaging, others may need a refresher during cardiac fellowship. In general, the higher the training level in imaging the fellows are aspiring to, the more familiar they should be with these principles.

Mathematics: It is assumed that all incoming fellows should be quite facile with basic arithmetic and basic and intermediate algebra. Additionally, there should be a working knowledge of trigonometry, including the meaning and use of sine, cosine, tangent, and their inverses. Fellows should be conversant with both Cartesian and polar graphing techniques, including such terms as ordinate and abscissa, and the convention for defining angles in polar plots as counter-clockwise from the positive x-axis. While not absolutely essential to Level 1 or 2 training, all fellows are strongly advised to be conversant with the techniques of differential and integral calculus. In addition, an understanding of Fourier analysis, in particular the interplay between the spatial and temporal domain, will prove of immense value in acquiring an intuitive understanding of Doppler ultrasound and CMR as well as tomographic reconstruction using filtered back-projection in CT and nuclear cardiology.

Physics: A strong physics background is perhaps the most important attribute when learning the various imaging techniques. As part of their medical school prerequisites, most fellows will have taken a 1-year college-level physics course, which should provide a working knowledge of Newtonian mechanics as well as the basics of electricity and magnetism.

From Newtonian solid-body mechanics, they should be familiar with Newton's Laws of Motion and application of the laws regarding conservation of mass, momentum, and energy. Solid mechanics can be generalized to include fluid mechanics, which would provide the fellow with the various forces affecting fluid flow, including pressure, viscosity, and fluid density. Fellows should also ideally be conversant with conservation of energy in the fluid domain (Bernoulli equation) as well as the principles relating pressure and volume inside of an elastic container.

In the area of electricity and magnetism, they should understand basic notions of voltage, current, and resistance and how to relate these through Ohm's Law, as well as basic electrostatics (such as the inverse square relationship between the distance between charges and the force attracting or repelling them). Fellows should know the basics of electrical circuitry, including direct and alternating current, and be familiar with the concepts of capacitance and induction. They should also be familiar with the laws governing magnetic forces, including static magnets, as well as those resulting from the passage of electrical current (electromagnetism).

All cardiovascular imaging modalities ultimately utilize electromagnetic or acoustic waves, and knowledge of wave mechanics will prove invaluable to the cardiovascular imaging trainee. Important in this background are notions of wavelength, period, wave velocity, and the interrelationships between these 3 entities. Trainees should understand that the speed of sound can change as it passes through various media, whereas the speed of light is fixed in all media. In addition, knowledge of wave reflection, refraction, and diffraction and the mechanism by which lenses work would be ideal.

Fellows are not expected to have a detailed knowledge of quantum mechanics, but this concept is so important in cardiovascular imaging that some familiarity would be very helpful. Ideally, the fellow would understand the duality between the wave and particle aspects of electromagnetic radiation and the interrelationship between electromagnetic frequency and photon energy through Planck's constant. Basic radiation physics would also be desirable.

Advanced manipulation of CMR images requires in-depth knowledge of physics and mathematics, and fellows desiring Level 3 training in this modality are advised to obtain and maintain as much physics and mathematics expertise as possible.

Practical Computer Knowledge: At least as important as mathematical and physical principles is a working knowledge of computer and network operations. This includes spreadsheet and database utilization and the basics of networking, including setting of internet protocol (IP) addresses and wireless technology. Image file manipulation utilizing lossless and lossy compression will prove helpful for educational and research purposes.

Anatomy, Physiology, and Pathology: It is assumed that any fellow emerging from an accredited medical residency program in the United States will understand enough cardiovascular anatomy to enter into a cardiovascular training program. Importantly, they should understand the relative magnitude of pressures and flows inside the heart; determinants of coronary flow and coronary flow reserve; the causes and consequences of various valvular, cardiomyopathic, and ischemic heart diseases; and the basic impact of acute ischemia and stress on cardiac function. In addition, trainees should be familiar with the anatomy of peripheral arteries and veins; understand the pathophysiology of arterial and venous diseases; and be knowledgeable about the consequences of peripheral arterial, aortic, carotid, renal, and mesenteric artery diseases and of venous thrombosis, stenosis, and insufficiency.

B. Basic Science Curriculum in Multimodality Cardiovascular Imaging

Currently the individual training requirements for echocardiography, nuclear cardiology, CCT, and CMR contain separate components of a basic science curriculum that include physics, radiation safety, instrumentation, and image acquisition, processing, and display. Although there are modality-specific content differences, there are also large areas of overlap in basic physics and computer sciences that provide the opportunity to consolidate both the teaching resources and time allocation for training in cardiovascular imaging. Not only is this consolidation efficient, it also provides the opportunity to create a true hybrid multimodality clinical cardiovascular imager who recognizes the strengths and weaknesses of each modality and can make an appropriate multimodality-informed decision as to which technique is best for answering a patient-specific clinical diagnostic or management question. This will discourage the temptation to select the modality with which the imager has the greatest familiarity rather than selecting the one that is most appropriate or to employ an unnecessary or redundant variety of tests to address a particular clinical need.

To that end, we propose to define the basic science knowledge base that contains both the common and modality-specific elements that are to be covered in the multimodality cardiovascular image training during a basic 3-year cardiovascular fellowship. It will replace current requirements for individual modalities. Some of these requirements extend beyond noninvasive imaging and are also required for training in general cardiology, cardiac catheterization, and electrophysiology. Some of the time saved by consolidating these general and imaging modality-specific requirements should allow for a more comprehensive imaging experience. There are, however, hurdles to the development and implementation of the basic science curriculum as discussed in the following text.

Definition of Content

Appendix 1 suggests a basic science and clinical application curriculum for training the multimodality cardiovascular imager. There are over 100 topic areas arranged first to address physical principles, safety, and computer technology, then including applications covering all modalities. It is doubtful that these topics would be covered in the precise order as listed. Instead, one might present basic applications after the introductory physics and instrumentation lectures, followed by more advanced physics and applications. Furthermore, a typical 1-h seminar may cover 1 or more topics, while some topics may require more than an hour of didactic instruction.

Recognition of Regulatory, Board, and Accreditation Requirements

Previous modality-specific COCATS imaging requirements have been used as eligibility requirements by federal and state regulatory agencies, physician certification boards, and laboratory accreditation bodies. The combined COCATS multimodality cardiovascular imaging basic science and laboratory curriculum needs to be compliant with the existing requirements. The United States Nuclear Regulatory Commission (NRC) and the Agreements States have recognized Level 2 training for licensure as a medical authorized user in nuclear cardiology, and continuation of these specific requirements is crucial. Since physician certification boards in nuclear cardiology and CCT have specifically required COCATS Level 2 training in these modalities for examination eligibility, every effort must be made to meet and continue these requirements. Dialogue must be established with these bodies to notify them of changes and to understand any potential impact of the changes on trainees.

Challenges to Practical Implementation of the Basic Science Curriculum

The creation and implementation of a multimodality basic science didactic and clinical laboratory experience curriculum presents tremendous, but not insurmountable, challenges to cardiovascular training programs. The first hurdle is incorporating the curriculum into a comprehensive 3-year program rather than the existing pattern of acquiring ultrasound principles during a rotation in echocardiography and radioisotope theory during a nuclear cardiology rotation. In some training programs the modality and the basic scientists to teach these various units do not exist. Training programs need to be flexible during early implementation for trainees to possibly pick and choose "à la carte" the basic science blocks for an individual modality if the trainee does not want or the program cannot provide advanced training in all areas. Some training programs with limited resources may choose an in-depth 1-year experience for a limited dedicated group of fellows, while others may be able to provide full training in all areas over the course of 3 years. The use of academic or consultative health physicists to teach the curriculum should be considered if sites lack adequate staffing. This proposed curriculum may also provide opportunities for professional organizations such as the ACC, ASE, ASNC, SCCT, SCMR, and SVM to provide disk- or web-based educational materials to supplement in-house education.

C. Imaging Applications

There are numerous clinical areas for which noninvasive cardiovascular imaging technology may be useful. These include: diagnosis of asymptomatic coronary atherosclerosis; assessment of patients with chest pain; noninvasive detection of coronary anatomic stenoses; quantifying extent of stress-induced ischemia and/or left ventricular (LV) dysfunction; assessing myocardial viability; identifying patients with high-risk CAD; determining prognosis in patients with CAD; identifying coronary artery anomalies; evaluating efficacy of coronary revascularization and anti-ischemic medical therapies; detecting restenosis after percutaneous revascularization and graft patency in coronary bypass patients; assessment of patients with dyspnea of uncertain etiology; determining the etiology of global LV dysfunction and heart failure; quantifying the extent of myocardial scar;

diagnosing and determining the severity of valvular heart lesions; assessment of pericardial abnormalities; assessment of simple and complex congenital heart disease; determining the hemodynamic consequences of heart disease; detecting abnormalities of the great vessels, peripheral arteries, and veins; and assessing the outcome of percutaneous and surgical interventions.

The objective of an imaging procedure is to provide accurate and clinically relevant information for a given patient. Because each technique has its strengths and limitations, an essential component of training is to learn the advantages, disadvantages, risks, and benefits of each of the imaging modalities in each individual clinical situation. There are 2 questions that must be answered. First, should an imaging test be performed and, if so, which test is most likely to provide the most accurate, cost-effective, and relevant diagnostic and prognostic value? Second, how should the images be acquired and interpreted, and how should the results be communicated to optimize the test's value? In the course of multimodality training, emphasis should be placed on the appropriate application of technology to provide the safest, most efficient, cost-effective, and complete approach to diagnosis. This may be the most important aspect of Level 1 training: to allow future nonimaging cardiologists to be educated consumers of imaging tests. While it is natural for mentors to devote attention to fellows committed to an imaging career, they must not neglect the larger group of trainees who will pursue other interests.

The current cardiovascular imaging modalities offer substantial versatility and flexibility for the evaluation of most clinical questions. An important part of the training experience is to acquire an appreciation for the utility of each test to address common clinical scenarios. The clinical portion of the training in cardiovascular imaging should include didactic lectures, hands-on experience, and supervised interpretation of imaging studies. Ideally, this training in multiple modalities should occur "in parallel" rather than "in series," at least after an initial stage of exposure. That is, simultaneous involvement in the different technologies offers the opportunity to compare and contrast each modality's inherent strengths and limitations. It should be recognized that the acquisition of knowledge and experience in one modality may carry over and serve as relevant background in other areas. For example, learning the relationship between coronary anatomy and segmental LV function in the nuclear laboratory will have relevance to the trainee learning stress imaging in all modalities. To the greatest degree possible, the common themes across modalities should be incorporated into the educational experience to improve the efficiency of training and to minimize redundancy.

The versatility of the different techniques permits the training experience to cover a wide range of clinical applications, including the broad categories of anatomy, function, metabolism, and hemodynamics. Many applications, such as measuring global LV systolic function, can be addressed by all modalities. The trainee should be exposed to each and should gain an appreciation for the relative strengths and limitations of the different techniques. Other applications, such as measuring the pressure gradient across a stenotic valve or quantifying a coronary lesion, are best evaluated by only 1 or 2 of the modalities. The trainee should become familiar with the range of applications covered by each technique and the patient-specific factors that make a given modality more or less applicable.

D. Requirements for Laboratories

Imaging modalities have evolved over the years as separate entities. Therefore, at this time, there is no single agency or standard of accreditation for all imaging laboratories, technical staff, or medical staff. However, training should occur in entity-specific laboratories (cardiovascular ultrasound, nuclear cardiology or nuclear medicine, CMR, and CCT) at an institution that has ACGME certification for training in cardiology and also in radiology, if fellows are rotating in facilities under cardiovascular radiology supervision. There are 3 components to each training environment: Medical Director Certification, Technical Staff Certification, and Laboratory Accreditation.

Medical Director: The medical director of each cardiovascular imaging training laboratory should be Level 3-trained in the specific diagnostic imaging modality. It would be optimal if the director has passed any available certifying examination as well as been board certified in their specialty and subspecialty, when available. The medical director should preferably also be involved in active research and participate in ongoing continuing medical education in that imaging modality.

Technical Staff: Most of the technical staff should be certified by the appropriate certifying body. Importantly, the technical director should be certified. The staff should meet ongoing continuing education requirements for current registration.

Laboratory: The optimal training site should have a standardized reporting system and preferably have digital storage and electronic structured reporting. The laboratory should be accredited by an appropriate, respective regulatory body such as the Intersocietal Accreditation Commission. Note that nuclear medicine sites must also be licensed by the NRC for use of radioactive materials.

If training in a specific modality is not available at a training site, trainees seeking Level 2 or 3 training should be sent to another program that meets all of the above standards. Even this recommendation may be difficult to implement until a sufficient number of training programs develop expertise in all modalities.

V. Training Requirements Specific to Imaging Modalities

While there are many common themes among the various imaging modalities, there remain very distinct modality-specific requirements, which must be addressed in any comprehensive training program. The detailed requirements in each modality are published in COCATS (1) and will not be reproduced here. Rather, this section will highlight the modality-specific aspects that will likely remain intact even in a multimodality training environment.

A. Cardiovascular Ultrasound

Physical Principles

Ultrasound is unique among the modalities in that it involves imaging by reflected energy. Trainees need in-depth instruction in the generation of ultrasound, its interaction with matter (transmission, reflection, refraction, attenuation, scattering, and so on), and the manner in which images are generated from the reflected ultrasound. Instrumentation issues will include power, gain, compression, time-gain compensation, and post-processing algorithms to generate M-mode and 2- and 3-dimensional images. Understanding the Doppler principle and the Nyquist sampling theory will allow application of pulsed, continuous wave, color flow, and tissue Doppler echocardiography. Recognition and avoidance of artifacts is crucial in ultrasound, including mirror, reverberation, side-lobe, refraction, range ambiguity, and beam-width artifacts. The physical principles of harmonic imaging and parallel processing should be understood. The effects of the various imaging techniques on tissue signal properties should be understood in order to avoid misinterpretation of these images.

Because the ultrasound examination is operator-dependent, with the potential to omit important diagnostic information and/or introduce confounding artifacts, fellowship training must include considerable hands-on experience. The ability to perform an ultrasound study independently and provide on-line interpretation of findings is an essential component of fellowship training. The trainee should develop sufficient technical skills to use an ultrasound instrument to answer common clinical questions.

Training in Echocardiography

As outlined in Table 1, even in an efficient multimodality environment, all cardiovascular trainees will require at least 2 months of dedicated training in echocardiography for Level 1 and 4 months for Level 2 certification. During that time, they should personally perform 75 and 150 cases (Levels 1 and 2, respectively) in addition to participating in their interpretation. More important than simple numbers is a robust case mix that provides the trainee with practice in all echocardiographic techniques in a wide variety of cardiovascular disorders. Key skills in which to obtain hands-on competency include assessment of global and regional left and right ventricular systolic function; characterization of diastolic function, requiring integration of information from transmitral and pulmonary venous flow, tissue Doppler annular velocities, and other modalities; quantification of stroke volume by pulsed Doppler and 2-dimensional methods; quantification of valvular stenosis, including the Bernoulli, pressure half-time, and continuity equation; assessment of valvular regurgitation, including color jet methods, proximal convergence, vena contracta, pulmonary vein and aortic arch flow reversal, and others; characterization of pericardial disease; basic assessment of congenital heart disease anatomy and physiology; and assessment of the great vessels. Hands-on training must be supplemented by dedicated mentoring in a similar number of diagnostic cases across the widest possible breadth of pathology.

Adequate training in echocardiography further depends on exposure to special procedures, including transesophageal echocardiography (TEE) and stress, 3-dimensional, and contrast echocardiography. Specific requirements for competency in each of these modalities have been established and published in COCATS (1). The trainee's experience in TEE should include an exposure to the intraoperative environment, where both routine monitoring and real-time evaluation of surgical results are encountered.

Training in Vascular Ultrasound

Although vascular ultrasound shares most physical principles and acquisition techniques with echocardiography, special training is needed in linear and curved transducer technology, B-mode, color, and spectral Doppler optimization, and venous and arterial anatomy and pathophysiology. The trainee should learn how to assess venous thrombosis, stenosis, and insufficiency and arterial stenosis in native arteries, bypass grafts and stents, and to recognize arterial pseudoaneurysms and arterio-venous fistulas. Measurement of carotid intimal-medial thickness should also be taught.

COCATS mandates a 1-month vascular medicine experience within the core cardiology fellowship. During this time, the trainee should be exposed to at least 50 vascular studies to achieve the equivalent of Level 1 training (within COCATS, vascular ultrasound does not specify training levels). While hands-on acquisition is not mandated for this initial exposure, it is strongly encouraged. Advanced training (again, COCATS does not differentiate between Level 2 and 3 training in vascular ultrasound) in vascular ultrasound must include supervised hands-on acquisition and interpretation in a wide range of vascular pathology: duplex ultrasonography of 1) the veins and arteries of the upper and lower extremities; 2) the aorta; 3) the renal and mesenteric arteries and veins; 4) the carotid arteries; and 5) infrainguinal bypass grafts. COCATS and Intersocietal Accreditation of Vascular Laboratories (ICAVL) (http://www.intersocietal.org/icavl/apply/standards.htm) guidelines for case numbers must be followed to assure competence. These include 100 venous duplex examinations, 100 carotid artery duplex examinations, 100 arterial duplex examinations, and 75 visceral vascular (arterial or venous) duplex examinations. This experience should be gained over a period of at least 3 months.

B. Nuclear Cardiology: SPECT, PET, and CT Hybrid Systems

Physical Principles

Nuclear cardiology uses radioisotopes attached to molecular markers that allow unique imaging of perfusion, innervation, inflammation, and other important physiological processes. The use of radionuclides requires an understanding of radiation physics, radiochemistry, gamma cameras, PET cameras, and CT systems. Relative to other modalities, the relatively low information density, poor spatial resolution, and relatively long image acquisition time for SPECT and PET mandates an in-depth understanding and unique appreciation of signal amplification, filtering, and the potential artifacts relative to other noninvasive modalities. The use of hybrid SPECT-CT and PET-CT systems provides an opportunity to use CT for accurate attenuation correction and improved spatial localization. Basic principles of CT imaging can be learned as part of the CCT training. Detailed requirements for training in nuclear cardiology are found in the recent COCATS document (1).

Training in Nuclear Cardiology

Nuclear cardiology training consists of 3 components: a didactic program with lectures, self study, and radiation safety; interpretation of clinical cases; and hands-on experience involving clinical cases and radiation safety. These components are detailed below.

As outlined in Section IV.B. and in the Appendix, the didactic program is composed of lectures on the basic aspects of nuclear cardiology. In addition to the topics listed previously under Physical Principles, this program should provide the fellow with an in-depth understanding of radiation safety as it relates to patient selection and administration of radiopharmaceuticals and nuclear medicine acquisitions (including SPECT, PET, and hybrid SPECT/CT and PET/CT systems). Classroom and laboratory training need to include a review of radiation physics and instrumentation, radiation protection, mathematics pertaining to the use and measurement of radioactivity, chemistry of byproduct material for medical use, radiation biology, the effects of ionizing radiation, and radiopharmaceuticals. There should be a thorough review of regulations dealing with radiation safety for the use of radiopharmaceuticals and ionizing radiation.

Fellows acquiring Level 1 training should have hands-on supervised experience with a minimum of 35 patients. A reasonable distribution of these is 25 patients with myocardial perfusion imaging and 10 patients with radionuclide angiography, although it is recognized that radionuclide angiography is declining in use and may not be performed in all hospitals. Such experience should include pre-test patient evaluation, choosing the appropriate stressor for testing, radiopharmaceutical preparation (including experience with relevant radionuclide generators and CT systems), performance of studies with and without attenuation correction, selection and administration of the proper dosages, calibration and setup of the gamma camera and CT system, setup of the imaging computer, processing the data for display, interpretation of the studies, and generating clinical reports. Fellows should be familiar with proper quality assurance procedures in the acquisition of an image and recognition of artifacts that can degrade image quality and diagnostic accuracy. In addition, 100 cases should be interpreted in a mentored setting for Level 1 training and 300 and 600 cases for Levels 2 and 3, respectively. During training, fellows should actively participate in daily nuclear cardiology study interpretation under the direction of a qualified preceptor in nuclear cardiology, and these studies should be integrated with correlative noninvasive modalities, such as CCT, echocardiography, and CMR, or invasive techniques. Although experience in all aspects of nuclear cardiology is recommended, some procedures may not be available—or may be performed in low volume—in some training programs. Under such circumstances, an adequate background for general fellowship training can be satisfied with appropriate reading or review of case files.

To achieve Level 2 training in nuclear cardiology, fellows should spend a minimum of 700 hours in nuclear cardiology to qualify as an "authorized user" (AU) of medical isotopes in accordance with the regulations of the NRC and/or the Agreement States, as outlined legally in 10 CFR Part 35.200. The extent and curriculum for this practical experience and safety training is detailed in COCATS (1), which must be rigorously adhered to. Simply stated, this requires: 1) 80 h of didactic classroom and teaching laboratory training as described previously; and 2) a further 620 h in a nuclear medicine laboratory gaining independent competence in safe clinical radioisotope handling through work experience while also learning instrumentation and scan interpretation. The preceptor should be an authorized user recognized by the NRC or an Agreement State, should have Level 3 (or the equivalent) training in nuclear cardiology, and should preferably be certified by the Certification Board of Nuclear Cardiology (CBNC). The clinical radiation safety hours must be monitored and verified by the nuclear cardiology training preceptor. The didactic training in radiation safety and radioisotope handling may be provided by qualified physicians/scientists in a non-ACGME program when such a program is not available as part of the clinical ACGME training program.

C. Cardiovascular Magnetic Resonance

While the skills required for CMR have substantial overlap with other modalities (particularly echocardiography and CCT), many aspects are unique to CMR and must be taught in a dedicated fashion. Detailed requirements for CMR training and competency are provided in COCATS (1) and the recent ACC/AHA competency statements for cardiac (2) and vascular (3) CCT and CMR.

Physical Principles

Trainees must learn the physical principles of CMR to a level consistent with their desired level of competence. Basic training in CMR should provide an understanding of the relationship between clinically relevant magnetic field strengths (i.e., from 1.5- to 3.0-T), the alignment of nuclear magnetic moments, and the magnitude of radiofrequency energy. To generate an image, it must be understood that superimposed magnetic field gradients must be employed. A critical issue to learn is proper safety procedures for both patients and testing personnel when working with clinical magnetic fields and radiofrequency fields as well as the contraindications to performance of CMR. Even Level 1 training should include familiarity with the basic hardware components of the CMR imaging system, including the superconducting magnet, radiofrequency coils, gradient coils, receiver coils, and digital/computer components.

For more advanced training, trainees should learn the physical basis for clinical CMR imaging, including the Larmor frequency, use of radiofrequency energy to "tip" nucleons (generally protons) out of alignment within the net magnetic field, and nucleon localization by applying linear gradients within the field of view. Trainees should understand the meaning of T1, T2, and T2* relaxation parameters and the way in which each of these contribute to the optimal generation of an imaging study. They should understand that the distribution of resultant frequencies is displayed in a domain called k-space, and that when the k-space image is subjected to Fourier transformation, it is converted into the spatial domain or an image. They should understand the principles of spin echo and gradient echo imaging, as well as the optimal pulse sequences for various applications such as steady-state free precession (SSFP) frequently used to depict the cardiac chambers. They should understand that the motion of blood affects the brightness of the signal and that the blood velocity can be encoded within an image to allow quantification of stroke, shunt, and regurgitant volumes. Paramagnetic contrast agents (generally chelates of gadolinium) increase the brightness of the signal where they localize, and trainees should know safety aspects of these agents as well as their use in CMR coronary and peripheral angiography, perfusion imaging, and imaging of myocardial scar.

Training in Cardiac Magnetic Resonance

As detailed in COCATS, Level 1 training in the cardiac aspects of CMR requires mentored participation in the interpretation of 25 cases, while Level 2 requires a total of 150 cases of which 50 must be acquired with the active participation of the trainee. Level 3 case requirements are double those of Level 2. Even more important than the number of cases is the case mix studied, so that the trainee will be equipped to assess the wide range of cardiovascular anatomy and pathology experienced in a CMR laboratory. Trainees require extensive practical experience both in guiding acquisition of CMR images and in interpreting them with off-line workstations. Fellows should have direct involvement in prototyping studies to determine which views and pulse sequences are likely to answer the clinical question, then use scout images to guide final acquisition and additional images as needed. Training must include acquisition of knowledge and skills regarding tissue parameters to highlight, including the relaxation times T1 and T2, proton density, flow (related to turbulence), and the presence of contrast agents, as well as the pulse sequences required for each CMR application. General imaging approaches to master include assessment of function (cine and tagged cine magnetic resonance including SSFP imaging approaches) at rest and during pharmacologic stress; determination of myocardial mass, ventricular volumes, and ejection fraction (using cine magnetic resonance imaging); and flow imaging (e.g., phase velocity encoded techniques) to assess cardiac output, shunts, and valvular regurgitation. Contrast is crucial to many types of CMR, and trainees should learn the types, mechanisms, and pharmacologic and toxic aspects of paramagnetic and superparamagnetic contrast agents; imaging of myocardial infarction or fibrosis (late gadolinium-enhancement imaging); contrast and noncontrast CMR methods for assessment of myocardial viability; cardiomyopathies; pharmacologic stress-testing with evaluation of ventricular function and/or first-pass perfusion imaging using paramagnetic contrast agents; pericardial diseases; and CMR coronary imaging and angiography, as detailed in the following text. Trainees should also be exposed to advanced CMR image analysis and post-processing tools and magnetic resonance spectroscopy methods (e.g., depth-resolved surface coil spectroscopy and 3-dimensional Fourier transform approaches). The clinically relevant alterations in signal properties between 1.5- and 3-T field strength should be understood, as well as the impact on image interpretation.

Training in Noncoronary Magnetic Resonance Vascular Imaging

Contrast enhanced magnetic resonance angiography (MRA) allows evaluation of large anatomic segments (e.g., from the aortic arch to the circle of Willis). MRA allows accurate evaluation of extracranial, thoracic, abdominal, and peripheral vessels. MRA of the noncoronary vasculature requires additional knowledge of anatomy as well as the pathophysiology of each vascular bed. The trainee should learn how to assess arterial and venous diseases including acute aortic syndromes (aortic dissection, aortic intramural hematoma, and penetrating aortic ulcer); aortic aneurysm (including mycotic aneurysm); aortic occlusive disorders; atherosclerotic and other diseases of the carotid, mesenteric, renal, and limb arteries; venous thrombosis; and vascular anomalies.

To achieve Level 2 training in peripheral vascular MRA imaging, the trainee should participate in the acquisition and interpretation of MRA images in an additional 50 cases under supervision and interpret the images from an additional 100 cases (over the 150 case requirement for cardiac

MRI) specifically involving diagnosis of peripheral vascular disorders. The COCATS document does not cite specific caseload requirements for training in peripheral vascular MRA imaging. Instead, these numbers are based on criteria for extracardiac MRA in the ACCF/AHA clinical competence statement on vascular imaging with CT and MR (3).

D. Cardiovascular Computed Tomography

Although the cognitive skills required in CCT largely overlap with angiography, CMR, cardiovascular ultrasound, and nuclear imaging, several aspects of CCT are unique to the field and must be taught in a dedicated fashion. Detailed requirements for CCT training and competency are provided in COCATS (1) and the recent ACC/AHA competency statements for cardiac (2) and vascular (3) CCT and CMR.

Physical Principles

CCT uniquely performs computer reconstruction of cross-sectional images from thin, fan-shaped X-ray beams passing through the body at many angles. Trainees must learn theoretical and practical aspects of the CCT scanner and image reconstruction, including a detailed appreciation for radiation safety. Concepts to be covered include the Hounsfield unit (X-ray attenuation relative to water), scan collimation, temporal resolution, table speed, field of view, window and level settings, and recognition of artifacts caused by motion, slice misregistration, partial volume effects, beam hardening, and image noise. Based on the above principles, training must include proper patient selection and patient preparation for cardiac CT procedures and contraindications for performing cardiac CT. Intensive training on a variety of CCT workstations is required for any application. Training must include study acquisition and image interpretation through 3- and 4-dimensional data manipulation, multiplanar reconstruction, maximum intensity projection, and volume rendered methods.

Training in Cardiac Computed Tomography

Level 1 training in CCT requires participation in the mentored interpretation of 50 cases, while Level 2 requires a total of 150 cases of which 50 must be acquired with the active participation of the trainee. Level 3 case requirements are double those of Level 2. These requirements are the same as the ACC/AHA competence statement for cardiac imaging with computed tomography and magnetic resonance (2) (50 active cases instead of 35 as specified in COCATS). Even more important than the number of cases is the case mix studied, so that the trainee will be equipped to assess the wide range of cardiovascular anatomy and pathology that is becoming the realm of CCT. A few key techniques and pathologies to be included during training are detailed in the following text.

Coronary Calcification: Trainees must learn the practical technique for acquiring calcification data and calculating this score while understanding the short- and long-term implications of the findings. Fellows must understand the technical limitations of coronary calcification, including its potential effect on quality of CCT angiography.

Coronary Anatomy: The important technique of CCT coronary angiography will require extensive training in proper visualization techniques, normal and abnormal coronary anatomy, recognition of native coronary stenosis, anomalous coronary arteries, coronary arterio-venous fistulas, and approaches to plaque characterization. Optimization of contrast injection and timing of data acquisition for assessing various cardiac structures, including left- and right-sided chambers, valves, coronary arteries, and veins as well as the great vessels must be learned.

Other Applications: Trainees must learn standardized measurement techniques for assessing size and function of the left and right ventricles, the atria, and great vessels. LV mass measurements should also be learned. Recognition of myocardial scar and intracavitary thrombi and masses should be taught. Fellows should also learn a structured approach to the anatomy of the cardiac valves, congenital anomalies, acquired pathology, and extraction of relevant information to aid in planning surgical or interventional procedures. Proper technique for assessing the pulmonary vasculature along with cases of pulmonary hypertension and pulmonary embolism should be taught. Finally, recognition and assessment of pericardial effusion, thickening, and calcification should be included, along with localization of the effusion or constriction to guide intervention.

Training in Peripheral Vascular Computed Tomography

As cardiovascular specialists, cardiology fellows are expected to acquire knowledge of vascular diseases beyond the heart and coronary arteries. For Level 2 training in vascular CT, the trainee should have mentored experience in the interpretation of CT images from 50 cases and interpret an additional 100 cases (above the 150 cases required for Level 2 training in cardiac CT imaging). Among the vascular disorders and interventions with which the trainee must have experience in interpretation are: diseases of the aorta such as aortic dissection, aortic intramural hematoma and penetrating aortic ulcer, aneurysm, and atherosclerosis; diseases of the limb, carotid, mesenteric, and renal arteries; venous thrombosis and other veno-occlusive disease; and peripheral bypass grafts, open and endovascular aortic repairs, and other interventions. These guidelines are consistent with the training pathway for noncardiac CT provided in the ACCF/AHA competence statement (3) and supersede the lower caseload requirements specified in COCATS.

E. Incidental Noncardiac Findings During Cardiovascular Imaging

The primary objective of cardiovascular imaging is the examination of the heart and blood vessels. Accordingly, cardiovascular imaging protocols may be suboptimal for the evaluation of extracardiac and extravascular structures. The members of this task force, in support of quality patient care, recommend that Level 2 or higher training in all modalities should include specific lectures and formal review of cases that demonstrate a variety of noncardiac pathologies in order to recognize incidental abnormalities and make appropriate referrals.

VI. Optimizing Training in Imaging Within a 3-Year Cardiology Fellowship

In order to develop an integrated approach to training in multimodality cardiovascular imaging, it is worthwhile to review the current COCATS requirements (1). For the 36-month cardiovascular fellowship period, no fewer than 7 months must be devoted to noninvasive imaging, of which at least 3 months are spent in echocardiography and 2 months in nuclear cardiology, with a highly recommended, but not required, 1 month each in CCT and CMR. With the standards established by these modalities, this training period allows only Level 1 training in echocardiography and nuclear cardiology. However, most fellows seek Level 2 training (to allow independent interpretation of studies) in echocardiography (3 additional months), while many gain independent competency in nuclear cardiology with at least 2 additional months along with the didactic physics material required for radiation safety. Currently, relatively few achieve competence in CCT or CMR.

It is highly desirable to evolve to a training paradigm in which all cardiology fellows achieve near Level 2 training in echocardiography with Level 1 training in nuclear cardiology, CCT, and CMR within the 7 months currently earmarked for noninvasive imaging in the 36-month categorical fellowship. This should be considered a minimal expectation. Fellows interested in cardiovascular imaging should be strongly encouraged to pursue additional training in noninvasive imaging, with an ultimate goal of Level 2 training in all 4 imaging modalities within their basic fellowship period, perhaps with 6 to 8 additional elective months of training.

The only way either of these goals can be achieved is by capitalizing on synergies among the physical principles and clinical applications of the various modalities as well as opportunities for extending image interpretation skills on various clinical rotations. Among the technological advancements driving these synergies is digital storage of all images and accessible review on multimodality, multiplatform display stations. This way, for example, fellows may increase their echocardiography skills during a CMR rotation; CCT and nuclear cardiology may be learned in the same reading session. Furthermore, any patient admitted to the Coronary Care Unit or general cardiology service will provide a rich opportunity to hone diagnostic skills with multiple imaging studies without redundancy or unnecessary cost. It is clear, however, that while synergies do exist between modalities, each has specific technical requirements that can only be learned with dedicated hands-on training. Thus, in the initial period of training in each modality, the fellow needs extensive, in-depth focused experience in imaging, unencumbered by other clinical duties.

Perhaps the most demanding modality from a manual acquisition aspect is echocardiography, which will require at least 2 months of training in both hands-on image acquisition and interpretation under the guidance of a Level 3-trained mentor with a curriculum as outlined in Section V.A. above and in Table 1. Within this period of time, it is likely that the fellow will perform the 75 studies and interpret the 150 studies considered necessary for Level 1 training. Similarly, basic training in nuclear cardiology requires skill in administration of the exercise or pharmacologic stress test, radiopharmaceutical preparation and injection, and study analysis, including recognition of artifacts. This will take at least 1 month of dedicated training by a Level 3-trained mentor. In CCT, dedicated training in specific acquisition protocols, avoidance of motion and arrhythmia artifacts, and interaction with various visualization and analysis programs will require at least 1 month of dedicated training. Finally, CMR imaging presents special challenges, since advanced application of this modality requires extensive knowledge of the physical principles involved in image acquisition, which is likely to be beyond the capability and needs of Level 1 training. For basic education of fellows not continuing on in imaging, an introduction to CMR should focus on the types of scanning approaches available, an understanding of the indications and contraindications for the technique, and the ability to appreciate information from basic CMR images and cine loops. This will require 1 month of dedicated training. The remaining 2 months of the required 7 months for imaging could be shared between 2 modalities to round out a fellow's basic experience or could be focused on a single modality where specific skills are sought.

It is hoped that many fellows, at least those interested in imaging, will go well beyond this minimum to ultimately achieve Level 2 training in all 4 modalities. Note that under current COCATS guidelines (1), such training would require approximately 15 months in total (echo 6, nuclear 4, CMR 3, and CCT 2 months). The ability to reduce this overall time depends critically on the presence of integrated imaging centers where multiple modalities can be viewed, analyzed, and taught. Each of the modalities has set specific requirements in terms of the type and number of studies to be performed and analyzed, which must be respected in training. It is critical that the fellows be fundamentally involved in the interpretation of each study they seek "credit" for, and not simply attach their names to studies based on cursory review. There may be further opportunities for imaging education within clinical rotations where images can be viewed and interpreted with experts in each modality. Again, this must be active interpretation and collaboration with experts in that modality, not simply viewing the images while reading the expert's report. Training in ancillary techniques within these modalities (e.g., TEE within echocardiography, PET within nuclear cardiology) has its own requirements that must be respected.

Because training programs may vary in case volume of the individual modalities, in availability of newer modalities, as well as in integration of all imaging modalities, the efficiency of training in MMI cannot be predicted in advance. For example, a very busy echocardiography laboratory with abundant and varied pathology may be able to train fellows to Level 2 training in transthoracic echocardiography within 4 months, with an additional intensive month to qualify in TEE. Because many CCT and CMR centers are integrated, it may well be possible to achieve Level 2 training in both within 4 months of integrated training. However, this intensity of case volume exposure may not be available in all programs, and some modalities, such as CMR, may not be available in some centers. It is the responsibility of individual training programs to inform potential fellows at the time of application as to the capability of the program to provide the training described here.

Table 1 shows the existing requirements for training in cardiovascular imaging in traditional, separate, individual-modality imaging programs (1), as well as the new proposed requirements for training in cardiovascular imaging in the setting of an optimized multimodality training environment. Note that the case number requirements for each modality and level are maintained. The duration of training for each modality shows three numbers for each level of training in an a/b/c format. In this column, "a" refers to the total number of months needed for competency in that modality (typically matching the current COCATS requirements), "b" is the number of months that must be spent exclusively in that modality (in particular mastering image acquisition and patient safety), and "c" is the number of months that can be shared between the modality in question and another modality. In all cases, the total number of months needed for a modality is equal to the dedicated months and those shared between modalities (a = b + c). This approach draws on the efficiencies of training simultaneously in more than 1 modality while still emphasizing a strong foundation for training, essential for quality interpretation of studies once a trainee attains Level 2 training and beyond. The savings in the total duration of multimodality training compared to single modality training arises from the keen awareness of the task force that an optimum balance needs to be achieved between synergies of training, and thus the ability to train within a shorter period of time, and the competence in each modality that needs to be achieved by the trainee. Throughout the training period, it is important to emphasize quality improvement in all modalities and to review comparative literature with the aim of selecting the best test for a given clinical situation.

VII. Approaches to Advanced Training in Multimodality Cardiovascular Imaging

While all trainees in cardiovascular medicine will require exposure to all imaging approaches, some will be interested in emphasizing cardiovascular imaging as a subspecialty and thus will not only desire extensive training in echocardiography, vascular ultrasound, and nuclear cardiology, but also advanced training in the newer technologies of CCT and CMR. An advanced MMI training track should preferably also include important imaging approaches, such as molecular imaging of the myocardium and vasculature, and potential applications of stem cells or other novel therapies. Teaching of hybrid imaging approaches, such as PET/CT, SPECT/CT, and/or PET/MRI, should also be available.

Consideration should therefore be given to providing training in multimodality cardiovascular imaging as a subspecialty for a future career in academics or clinical practice. This evolution is similar to what has occurred in cardiac electrophysiology and interventional cardiology, in which thought leaders in these disciplines recognized that a unique body of knowledge needed to be learned with high technical proficiency to deliver the highest quality of care. The ACC and the AHA supported the concept of adding a fourth year of fellowship training leading to an examination under the aegis of the Cardiovascular Board of the American Board of Internal Medicine (ABIM). The parent ABIM board and subsequently the American Board of Medical Subspecialties (ABMS) agreed with the proposals from the cardiology community. The fourth year of training and relevant board examinations were thus established for advanced subspecialty training in electrophysiology and interventional cardiology where fellows who passed an examination given under the aegis of the ABIM could acquire a Certificate of Added Qualification (CAQ) in these disciplines. A similar process is currently underway for advanced training and certification in heart failure management.

To achieve the goals of advanced training in multimodality cardiovascular imaging, a formal fourth year of training would be necessary for fellows to gain further expertise in some or all of the 4 imaging modalities and become certified; this is being explored. This training experience would include an integrated program, building on the imaging curriculum of the categorical fellowship outlined in Section VI and teaching advanced physical principles and instrumentation of each cardiovascular imaging modality, with strong exposure to research aspects and evolving approaches to imaging. A new subspecialty board in cardiovascular imaging could be created, consisting of members representing the various imaging disciplines as well as general cardiology. The ACGME would need to approve fellowship training programs applying for the provision of training to fellows in this advanced cardiovascular imaging track, as has already been demonstrated for electrophysiology and interventional cardiology. While it is conceivable that a fellow could accomplish Level 3 training in all modalities in a single additional year beyond basic fellowship, this would require him/her to have spent essentially all elective time during the basic fellowship in imaging and planned accordingly very early in the fellowship training. Fellows wishing to remain in academic medicine should strongly consider a second additional year of training in imaging to fully encompass multimodality cardiovascular imaging and to acquire research skills necessary to become an authority in cardiovascular imaging. It should be noted that while some fellows in this advanced MMI track may wish to complete Level 3 training in all 4 imaging modalities, others may alternatively choose to be a "super-expert" in 1 or 2 of the modalities. The committee respects the choice of those who plan to pursue a career in cardiovascular imaging but wish to focus their clinical and/or research activities in a single modality. Those wishing to lead technical and clinical developments in a given modality may well find little time available for other modalities. A board examination might account for such choices by having a modular approach, with a general exam covering aspects deemed essential for all imagers to know, supplemented by advanced testing in each of the modalities as needed by an individual trainee.

A major outcome of such an advanced MMI training opportunity is that the cardiovascular imaging subspecialist would have the optimal knowledge base to select the best modality for a given clinical indication, to independently interpret MMI tests including complex fusion imaging, to head a cardiovascular imaging center, and potentially to lead innovations in the development and applications of cardiovascular imaging.

VIII. From Single to Multimodality Imaging: Suggestions for Training Programs

Training programs may add the necessary capabilities for training cardiology fellows in MMI at a different pace. Some programs have already attained this status, while others have not or are in the process of doing so. Training programs should examine which imaging modalities beyond cardiovascular ultrasound and nuclear cardiology they can offer to their trainees. If CCT and CMR training, for example, are not currently available, several options exist. These range from partnering with the radiology training program in the same institution, initiating a CCT/CMR program depending on the local environment and support, or alternatively, partnering with another training program that provides the needed training in the city or in a remote location, either as an interim solution or for the longer term. There may also be large nonacademic cardiovascular imaging centers nearby with which a training program could partner. These approaches, among others, provide environments for fellows to pursue training in the full range of cardiovascular imaging.

Educational offering for the trainees in MMI should follow along the lines of a comprehensive, cohesive, and efficient curriculum, similar to the one proposed in Appendix 1. This allows a better understanding of the advantages and disadvantages and appropriate utilization of imaging modalities with the emphasis on quality. Didactics, conferences, and case studies with computerized feedback of MMI reinforce learning and provide, where appropriate, fundamental information unavailable at the training site. The ACC and other organizations involved in education could provide such enduring educational material for training programs to utilize when necessary. For example, a web-based archive of useful teaching cases might be offered to the ACC from subspecialty organizations to provide an evolving set of informative clinical material, with basic to advanced examples of relevant cases.

With digital acquisition, storage, and retrieval, cardiovascular images from all modalities can now be reviewed in a single reading room and on clinical rounds. This highlights an increasing need for information technology support and the possibility of interpreting "on the fly," outside of the confines of a conventional reading room. While many studies can be reviewed in this manner, it is the recommendation of the task force that credit for interpretation should only be given to an in-depth review with an attending specialist in imaging. Simultaneous learning of imaging modalities must include sufficient time dedicated to basic principles of each modality and achieving competence in interpretation of studies. Competency in the modalities learned simultaneously needs to be evaluated by an assigned mentor for the rotation with an overall assessment of the milestones achieved. In the future, assessment of competency in MMI will need to go beyond this apprentice model (based on duration of training and case experience with a mentor) and shift to actual measurement and demonstration of multimodality competencies prior to completion of training.

An optimal setting for training in MMI is an integrated Cardiovascular Imaging Center, where most or all imaging modalities are housed in close proximity, sharing a centralized interpretation area. This is an ideal setting for performance of studies, for the training of fellows, and for interaction among faculty and fellows in the various imaging disciplines. Having multiple imaging modalities in close proximity can foster focus, expertise, and collaboration and even allow a change of one test for another if deemed more appropriate by the imaging specialist and trainee in consultation with the ordering physician. This setting also allows fellows to dedicate time to one modality or to simultaneously train in other modalities, and thus provides greater flexibility and efficiency. A combined reading room where fellows are exposed to most and preferably all imaging modalities as well as interaction with the respective faculty can provide tremendous opportunities for learning the intricacies of the methods and their comparative advantages and disadvantages. This arrangement undoubtedly improves the efficiency for fellows to tackle interpretation of studies by the various modalities and decreases the down time that is often observed between reading sessions. Furthermore, the enabled interaction allows sharing of information among experts in the various modalities. This is a fruitful ground for improved diagnostics, collaborative work, and research as part of the training experience. Increasingly, technology facilitates such a setting by providing work stations that will accommodate multiplatform viewing of cardiovascular images of more than 1 modality. While the above setup of an integrated imaging center may not necessarily be feasible in all training programs, having at least 2 modalities housed in close proximity with a common or adjacent reading room would still draw on the mentioned advantages, with the ultimate goal of a dedicated Cardiovascular Imaging Center.

To achieve MMI training, it is suggested that each fellowship program start by critically examining and evaluating its imaging personnel (cardiovascular faculty, radiology faculty, and expertise outside the training institution in the community or beyond) and resources (physical space, information systems, web-based and DVD educational modules, and local and national meetings). Existing laboratory directors should play a critical role in assisting the fellowship director in this inventory and subsequent planning process. Having taken this inventory, each program should re-examine its curriculum, schedule, and deployment of faculty and resources so as to provide Level 1 training in all modalities to all trainees. This can generally be accomplished within a 1-year period.

As a second phase, each program should extend the work noted above and plan to provide Level 2 training in each modality. Finally, each program should develop an opportunity for fellows to obtain Level 3 training in each modality, whether within the institution or at another training program, as well as develop the opportunity for selected fellows to obtain advanced training in order to become multimodality cardiovascular imaging experts.

Staff

Jack Lewin, MD, Chief Executive Officer
Charlene May, Senior Director, Science and Clinical Policy
Tanja Kharlamova, Associate Director, Clinical Policy and Documents
Erin A. Barrett, Senior Specialist, Science and Clinical Policy

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APPENDIX 1: ACCF 2008 TRAINING STATEMENT ON MULTIMODALITY NONINVASIVE CARDIOVASCULAR IMAGING

1. Introduction: clinical examples of cardiovascular images
   a) Ultrasound, CCT, nuclear, CMR

2. Imaging physics
   a) General concepts: spatial and temporal resolution, digital storage and review, parametric display, tissue contrast
   b) Electromagnetic radiation
      i) Intro: particles versus waves, photons, wavelength, frequency, energy, constancy of velocity
      ii) Generation of X-rays
      iii) Interaction of X-rays with matter
      iv) Fundamental aspects of X-ray image capture, processing, and resolution
      v) Biological effects of radiation, safety aspects
      vi) Radiation dosimetry
   c) Nuclear cardiology
      i) Generation of gamma-rays (electron capture, beta emission, positron emission)
      ii) Fundamental aspects of nuclear image capture, processing, and resolution
      iii) Data processing specific to radionuclide angiography, SPECT, PET, quantitation
      iv) Attenuation of gamma rays and approaches to correction
   d) Radiation safety work experience
      i) Ordering, receiving, and unpacking radioactive materials safely and performing the related radiation surveys;
      ii) Performing quality control procedures on instruments used to determine the activity of dosages and performing checks for proper operation of survey meters;
      iii) Calculating, measuring, and safely preparing patient or human research subject dosages;
      iv) Using administrative controls to prevent a medical event involving the use of unsealed byproduct material;
      v) Using procedures to safely contain spilled radioactive material and using proper decontamination procedures;
      vi) Administering dosages of radioactive material to patients or human research subjects; and
      vii) Eluting generator systems appropriate for preparation of radioactive drugs for imaging and localization studies, measuring and testing the eluate for radionuclide purity, and processing the eluate with reagent kits to prepare labeled radioactive drugs.

e) Ultrasound
   i) Intro: physical descriptions, determinants of velocity, differences from electromagnetic radiation
   ii) Generation of ultrasound and interaction with matter
   iii) Fundamental aspects of ultrasound image capture, processing, and resolution
   iv) Physics and instrumentation of Doppler ultrasound imaging
      (1) Advanced signal processing: Doppler tissue imaging, strain, speckle processing, 3D
   v) Transesophageal and intracardiac echocardiography
   vi) Vascular duplex ultrasonography
      (1) Doppler waveforms, spectral analysis, harmonics, aliasing, gray scale imaging, and processing
   vii) Biological effects of ultrasound, safety aspects of ultrasound and contrast agents

f) Magnetic resonance
   i) Intro: magnetic moments, sensitive nuclei (^{1}H, ^{31}P, ^{13}C, etc.), field strength, alignment in a magnetic field, precession, definition of T1, T2; spectroscopy versus imaging, determinants of image intensity: proton density, T1, T2, motion, ferromagnetic versus paramagnetic
   ii) Overview of instrumentation
   iii) Image formation: Fourier processing, gradients, k-space
   iv) Generating CMR images: spin echo, gradient echo imaging, slice selection, techniques to highlight T1, T2, T2*, contrast agents; image reconstruction
   v) Strategies for accelerated and real-time imaging, parallel methods, echo planar
   vi) Cartesian versus noncartesian acquisitions
   vii) MR spectroscopy, ^{1}H, ^{31}P, and other nuclei
   viii) Biological effects of magnetic fields, safety aspects of CMR and contrast agents, impact on devices

g) Computed tomography
   i) Instrumentation aspects and relation to standard X-ray imaging
   ii) Contrast resolution
   iii) Interaction of heart rate and image acquisition parameters and relation to image resolution and dosimetry
   iv) Safety aspects of CCT and contrast agents; strategies for radiation dose reduction

h) Contrast agents in imaging
   i) General principles
   ii) Angiography/CCT: iodinated contrast
   iii) CMR: gadolinium and other contrast agents
   iv) Echocardiography: saline and transpulmonary microbubbles
   v) Nuclear: SPECT and PET radionuclides

i) Image storage, review, and analysis
   i) Formatting standards: DICOM and others
   ii) Pre- and post-processing, low- and high-level image processing, contour and surface detection and rendering, feature extraction, assisted interpretation
   iii) 1D, 2D, 3D, 4D datasets with and without parametric overlays

j) Comprehensive approach to study interpretation and reporting
   i) Cardiovascular ultrasound
   ii) Nuclear cardiology
   iii) CCT
   iv) CMR

3. General imaging aspects
   a) Tomographic anatomy (examples from each modality)
      i) Geometric relationship among chambers
      ii) Left and right ventricular anatomy
      iii) Anatomy of the atria, atrial appendages, pulmonary veins, and cavae
      iv) Anatomy of the great vessels
      v) Vascular anatomy
      vi) Coronary artery anatomy, including coronary veins and coronary sinus
   b) 3D imaging
      i) Approaches to 3D data acquisition
      ii) Visualization and post-processing: how to navigate a 3D dataset

- c) Cardiovascular hemodynamics
  - i) General concepts: stroke volume, cardiac output, ejection fraction, pre-load, afterload, elastance, stress, strain
  - ii) Conservation laws in cardiology: mass (continuity equation), energy (Bernoulli equation), momentum (jet mechanics)
  - iii) Assessment of cardiac chamber size and mass
  - iv) Imaging aspects of systolic function
  - v) Imaging aspects of diastolic function
  - vi) Imaging aspects of valvular stenosis and regurgitation
  - vii) Imaging aspects of vascular function
- d) Coronary physiology
  - i) Determinants of coronary blood flow, impact of stenoses
  - ii) Behavior of imaging agents (thallium, sestamibi, tetrafosmin, gadolinium, ultrasound microbubbles, iodinated contrast)
- e) Exercise and the heart, impact of inotropic and vasodilator stress
  - i) Specific exercise protocols, pharmacologic stress, and vasodilator agents
- f) Vascular function and structure
  - i) General concepts of blood flow, resistance, impedance, compliance, and capacitance
  - ii) Ultrasound characteristics of arterial plaque and stenosis
  - iii) Imaging aspects of vascular function
  - iv) Imaging aspects of venous disease
- g) Multimodality imaging
  - i) Techniques of cross-registration of studies and fusion imaging

4. Specific imaging applications
- a) Coronary artery disease
  - i) Anatomical definition (angiography, CCT, CMR, ultrasound)
  - ii) Physiological impact
    - (1) Perfusion imaging with exercise and vasodilator stress (practical implementation of nuclear scanning, gadolinium-chelate and iodinated contrast first pass imaging, ultrasound contrast perfusion)
    - (2) Functional imaging with exercise and dobutamine echocardiography and CMR
  - iii) Chronic ischemic disease: assessment of viability with SPECT, PET, gadolinium CMR, dobutamine echo and CMR, ultrasound contrast perfusion
- b) Heart failure and cardiomyopathy
  - i) Choices in imaging
  - ii) Multimodality assessment of cardiomyopathies:
    - (1) Dilated
    - (2) Hypertrophic
    - (3) Infiltrative
  - iii) Diastolic dysfunction and heart failure
  - iv) Assessment of dyssynchrony and impact of resynchronization
  - v) Right heart failure and pulmonary arterial hypertension
  - vi) Assessment of cardiac transplant patients
- c) Congenital and acquired valvular heart disease
  - i) Mitral stenosis
  - ii) Mitral regurgitation
  - iii) Aortic stenosis
  - iv) Aortic regurgitation
  - v) Tricuspid valve disease
  - vi) Pulmonic valve disease
  - vii) Endocarditis
  - viii) Assessment of prosthetic valves
- d) Aortic disease
  - i) Anatomic definition
  - ii) Aortic aneurysms and dissections, coarctation

- e) Vascular disease
  - i) Peripheral arterial disease of the lower and upper extremities
  - ii) Carotid and intracranial artery disease
  - iii) Renal and mesenteric artery disease
  - iv) Assessment of subclinical atherosclerosis and plaque/stenosis
  - v) Assessment of vascular health
  - vi) Inflammatory arteritis
  - vii) Assessment of venous thrombosis and insufficiency
  - viii) Pulmonary emboli
  - ix) Assessment of pulmonary veins
- f) Congenital heart disease (CHD)
  - i) Embryology of cardiac structures
  - ii) "Simple" CHD: atrial septal defects, ventricular septal defects, coarctation, patent ductus arteriosus
  - iii) Complex CHD: single ventricle, transposition of the great arteries, truncus arteriosus, etc.
  - iv) Imaging anatomy of common CHD surgeries
  - v) Imaging palliated adults with CHD
- g) Pericardial disease
  - i) Effusion/tamponade
  - ii) Calcification, thickening, and constriction
- h) Artifacts and pitfalls for each modality
- i) Extracardiac findings
  - i) Strategies for handling extracardiac findings
  - ii) Introduction to extracardiac thoracic anatomy and pathology
  - iii) Pathologic findings within the imaging field
- j) Hybrid imaging platforms
  - i) General principles of coregistering imaging datasets
  - ii) Specific examples
    - (1) PET/CT
    - (2) Angio/CMR
    - (3) Merging real-time echo with CMR and CCT datasets
- k) Guidance of interventions
  - i) Intraoperative echo
  - ii) Guidance of catheterization laboratory procedures
  - iii) Guidance of electrophysiologic procedures
  - iv) Magnetic resonance in operating rooms and catheterization laboratories

5. Choices in imaging
   - a) Decision theory, Bayesian analysis: when should we do or not do a test?
   - b) Safety issues: radiation risks, contrast agents, how to balance risk versus benefit
   - c) Economic issues: how to balance cost versus benefit. What algorithms should be pursued to maximize yield for a given question?
   - d) Quality in imaging: how do we define it? How can we progressively improve?
   - e) Appropriateness criteria: defining the right time to do a test. When should tests be repeated?
   - f) Variability and reproducibility of quantitative results. Approaches to the development of laboratory-specific normal values.

Note: These topics are not meant to require a fixed lecture period to cover each one. A given topic may require several sessions or a single session may be able to cover several topics. Also, this curriculum may not include all material needed to fulfill licensure requirements in nuclear medicine. Supplemental lectures must be included to fulfill these requirements, as required by the individual states.

APPENDIX 2: AUTHOR RELATIONSHIPS WITH INDUSTRY—ACCF 2008 TRAINING STATEMENT ON MULTIMODALITY NONINVASIVE CARDIOVASCULAR IMAGING

Committee Member	Consultant	Speaker	Ownership/ Partnership/ Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Dr. James D. Thomas (Co-Chair)	• General Electric Healthcare • Philips Medical Systems, Inc. • Siemens Corporation	None	None	None	None	None
Dr. William A. Zoghbi (Co-Chair)	• General Electric Healthcare • Philips Medical Systems, Inc. • Siemens Corporation	None	None	None	None	None
Dr. George A. Beller	None	None	None	None	None	None
Dr. Robert O. Bonow	None	None	None	None	None	None
Dr. Matthew J. Budoff	None	• General Electric Healthcare	None	None	None	None
Dr. Manuel D. Cerqueira	None	None	None	None	• President of the Certification Board of Cardiovascular Computed Tomography, • Former President of the Certification Board of Nuclear Cardiology	None
Dr. Mark A. Creager	None	None	None	None	None	None
Dr. Pamela S. Douglas	• General Electric Healthcare	None	None	None	None	None
Dr. Valentin Fuster	• BG Medicine* • Chair, High Risk People • Chair, Foundation for Cardiovascular Education & Research • GlaxoSmithKline • Merck & Co. • Vasogen*	None	None	None	None	None
Dr. Mario J. Garcia	• BG Medicine • Philips Medical Systems, Inc. • Vital Images, Inc.	None	Pfizer, Inc.	• Philips Medical Systems, Inc.*	None	None
Dr. David R. Holmes, Jr.	None	None	None	None	None	None
Dr. Warren J. Manning	None	None	• Philips Medical Systems, Inc.*	None	None	None
Dr. Gerald M. Pohost	None	None	None	None	None	None
Dr. Thomas J. Ryan	None	None	None	None	None	None
Dr. William A. Van Decker	None	None	None	• Astellas Pharma US, Inc. • General Electric Healthcare	None	None
Dr. Susan E. Wiegers	None	None	None	None	None	None

This table represents the relationships of committee members with industry and other entities that were reported orally at the initial writing committee meeting and updated in conjunction with all meetings and conference calls of the writing committee during the document development process. It does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of 5% or more of the voting stock or share of the business entity, or ownership of $10,000 or more of the fair market value of the business entity; or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. A relationship is considered to be modest if it is less than significant under the preceding definition. Relationships in this table are modest unless otherwise noted.

*Significant (greater than $10,000) relationship.

APPENDIX 3: PEER REVIEWER RELATIONSHIPS WITH INDUSTRY AND OTHER ENTITIES—ACCF 2008 TRAINING STATEMENT ON MULTIMODALITY NONINVASIVE CARDIOVASCULAR IMAGING

Peer Reviewer	Representation	Consultant	Speaker	Ownership/Partnership/Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Dr. L. Kristin Newby	Official Reviewer—ACCF Task Force on Clinical Expert Consensus Documents	None	None	None	None	None	None
Dr. John Dent	Official Reviewer—ACCF Board of Governors	None	None	None	None	None	None
Dr. Miguel Quinones	Official Reviewer—ACCF Board of Trustees	None	None	None	None	None	None
Dr. James Arrighi	Organizational Reviewer—American Society of Nuclear Cardiology	None	None	None	None	None	None
Dr. Mylan Cohen	Organizational Reviewer—American Society of Nuclear Cardiology	• Astellas Pharma US, Inc. (No fees paid directly; all relationships paid to practice. After overhead, these would be shared by 20 partners)	None	None	• Point Biomedical	None	None
Dr. Stephan Achenbach	Organizational Reviewer—Society of Cardiovascular Computed Tomography	• Bracco Diagnostics • Servier	None	• Bayer Schering Pharma* • Siemens Healthcare*	None	None	None
Dr. David Bluemke	Organizational Reviewer—Society for Cardiovascular Magnetic Resonance	• General Electric Healthcare	None	None	None	None	None
Dr. Victor Ferrari	Organizational Reviewer—Society for Cardiovascular Magnetic Resonance	None	None	None	None	None	None
Dr. Herbert Aronow	Organizational Reviewer—Society for Vascular Medicine	None	None	None	None	None	None
Dr. Joshua Beckman	Organizational Reviewer—Society for Vascular Medicine	Bristol-Myers Squibb	• Bristol-Myers Squibb—Sanofi* • GlaxoSmithKline • Merck & Co. Inc.	None	None	None	None
Dr. Susan Begelman	Official Reviewer—Society for Vascular Medicine	None	None	• Nuvelo, Inc.*	None	• Nuvelo, Inc.*	None

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Peer Reviewer	Representation	Consultant	Speaker	Ownership/ Partnership/ Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Dr. Victor Froelich	Organizational Reviewer—Society for Vascular Medicine	None	None	None	None	None	• Expert witness in malpractice case regarding vascular imaging
Dr. Scott Kinlay	Organizational Reviewer—Society for Vascular Medicine	• Merck Co. Inc.* • Pfizer, Inc.	None	None	• Pfizer, Inc.*	None	None
Dr. John Hodgson	Content Reviewer—Cardiovascular Imaging Council	• Volcano*	• General Electric Medical • Volcano*	• Volcano*	• General Electric Medical* • Volcano*	None	None
Dr. Edward Martin	Content Reviewer—Cardiovascular Imaging Council	None	None	None	• General Electric Healthcare	None	None
Dr. Jay Silverstein	Content Reviewer—Cardiovascular Imaging Council	None	None	None	None	None	None
Dr. Greg Thomas	Content Reviewer—Cardiovascular Imaging Council	• Astellas Pharma US, Inc. • Cardiovascular Therapeutics • General Electric Healthcare	• Astellas Pharma US, Inc.	None	• Cardiovascular Therapeutics* • General Electric Healthcare* • Molecular Insight Pharmaceutics, Inc.*	None	None
Dr. John Mahmarian	Individual Content Reviewer	• Astellas Pharma US, Inc. • Digirad • Molecular Insight Pharmaceuticals, Inc.* • Philips Medical Systems, Inc.	None	None	• Cardiovascular Therapeutics, Inc.* • General Electric Healthcare* • Molecular Insight Pharmaceuticals, Inc.*	None	None
Dr. Rick Nishimura	Individual Content Reviewer	None	None	None	None	None	None
Dr. Nathanal Reichek	Individual Content Reviewer	None	None	None	None	None	None
Dr. Andrew Van Tosh	Individual Content Reviewer	None	None	None	None	None	None

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