Special Reports

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American College of Radiology Clinical Statement on Noninvasive Cardiac Imaging[1]

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GENERAL INTRODUCTION

Coronary artery disease (CAD) and other acquired and congenital cardiac diseases are major medical and socioeconomic problems. CAD affects 13.2 million Americans and was responsible for 502 189 deaths in 2001. In 2004, the direct and indirect economic impact of CAD was in excess of $120 billion, which was about one-third of the total costs attributable to cardiovascular diseases (1).

Historically, imaging has had a critical role in the diagnosis and evaluation of acquired and congenital cardiac disease, beginning with chest radiography and fluoroscopy and progressing to coronary angiography and cardiac catheterization, ultrasonography (echocardiography), and nuclear medicine. All of these modalities have a well-established role in patient care. Computed tomography (CT), with multidetector CT and electron-beam technology, and magnetic resonance (MR) imaging, with appropriately equipped imagers, now can image the coronary arteries, cardiac chambers, valves, myocardium, and pericardium and can help assess cardiac function. Thus, CT and MR imaging will have an increasing role in comprehensive cardiac imaging.

While the technical parameters and field of view of a cardiac CT or MR examination will appropriately be tailored to help evaluate the cardiac anatomy and/or function in question, the images obtained will demonstrate adjacent anatomy, often including portions of the lungs, mediastinum, spine, and upper abdomen. It has been documented that these studies often demonstrate clinically significant noncardiac findings (2,3). In addition to examining the cardiac structures of interest, the interpreting physician is responsible for examining all the visualized noncardiac structures and must report any clinically relevant abnormalities of these adjacent structures. In some cases, these structures may be seen only on localizing (scout) images.

Cardiac CT and cardiac MR imaging each present potential patient safety issues. Cardiac CT safety issues are related to radiation exposure and to administration of intravascular (IV) contrast media. The safety concerns for cardiac MR imaging are primarily related to the strong magnetic field and its potential effect on implanted devices, but MR imaging contrast agents and patient sedation also present potential safety issues. In addition, pharmacologic agents may be administered for either CT or MR imaging examinations.

Radiologists, because of their extensive experience in CT and MR imaging, have an important role in imaging of cardiac patients with these modalities. Most radiologists already supervise the performance of CT and interpret CT scans of the chest (including basic evaluation of the pericardium, heart size, and cardiac masses) and CT angiographic and MR angiographic images. Their knowledge of structures beyond the heart provides added value in cardiac imaging. They already oversee CT and MR imaging equipment and personnel. Their experience with the techniques now being applied to the heart provides expertise to develop specific cardiac applications of CT and

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MR imaging, and it shortens their learning curve for these cardiac applications.

The American College of Radiology (ACR) develops and revises practice guidelines and technical standards that address a wide range of imaging applications. Existing practice guidelines address many areas related to cardiac CT and MR imaging. These include the following: "ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography (CT)," "ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging (MRI)," "ACR Practice Guideline for the Performance and Interpretation of CT Angiography (CTA)," "ACR Practice Guideline for the Performance and Interpretation of Pediatric and Adult Body Magnetic Resonance Angiography (MRA)," "ACR Practice Guideline for the Performance of Pediatric and Adult Thoracic Computed Tomography (CT)," "ACR Practice Guideline the Performance of Computed Tomography (CT) for Detection of Pulmonary Embolism in Adults," "ACR Practice Guideline for the Performance of Cardiovascular Magnetic Resonance Imaging (MRI)," "ACR Practice Guideline for the Use of Intravascular Contrast Media," "ACR Practice Guideline for Adult Sedation/Analgesia," and "ACR Practice Guideline for Pediatric Sedation/Analgesia."

This clinical statement of the ACR discusses various technical and patient safety issues related to cardiac CT and MR imaging, and it suggests appropriate qualifications for radiologists until such time as ACR practice guidelines for the performance of cardiac CT and cardiac MR imaging are written and approved through the usual ACR process. Issues related to vascular CT and MR are addressed in documents listed in the preceding paragraph.

CARDIAC CT

Introduction

CT is a proven and important imaging modality for the detection and characterization of cardiac disease (4). CT may be used as either the primary modality for detecting disease or as an adjunct to other imaging modalities to better characterize disease and help assess change over time. CT can be used to assess both cardiac structure and function (5,6), as well as evaluate disease processes within the field of view but outside of the heart and pericardium (7,8).

Applications of cardiac CT include but are not limited to the following (5,9–17): *(a)* detection and characterization of coronary artery occlusive lesions secondary to atherosclerosis, transplant arteriopathy, intimal dissection, and vasculitis; *(b)* detection and characterization of coronary artery anomalies; *(c)* detection and characterization of coronary artery aneurysms; *(d)* coronary vein mapping; *(e)* characterization of cardiac chamber morphology and function; *(f)* characterization of native and prosthetic cardiac valves; *(g)* detection and characterization of congenital heart diseases; *(h)* characterization of cardiac masses; *(i)* diagnosis of pericardial diseases; and *(j)* detection and characterization of postoperative abnormalities.

Qualifications of Personnel

The Radiologist

The radiologist who supervises and interprets cardiac CT examinations should meet the following criteria for calcium scoring:

By virtue of experience and residency training, which has included cardiac anatomy and CT physics, a board-certified radiologist is qualified to perform calcium scoring of coronary arteries. It is expected that board-certified radiologists will be familiar with the indications and techniques for, as well as the interpretation of, coronary artery calcium scoring.

The radiologist should meet the following criteria for cardiac CT (not including examinations performed exclusively for calcium scoring:

1. Certification in radiology or diagnostic radiology by the American Board of Radiology, the American Osteopathic Board of Radiology, the Royal College of Physicians and Surgeon of Canada, or Le College des Medecins du Quebec and have supervised and interpreted 75 cardiac CT cases, excluding those performed exclusively for calcium scoring, in the past 36 months.

OR

Completed an Accreditation Council for Graduate Medical Education (ACGME)-approved radiology residency program and have supervised and interpreted 75 cardiac CT cases, excluding those performed exclusively for calcium scoring, in the past 36 months.

AND

2. Completed at least 40 hours of category I continuing medical education in cardiac imaging, including cardiac CT, anatomy, physiology, and/or pathology or documented equivalent supervised experience in a center actively performing cardiac CT.

Maintenance of competence.—All radiologists' performing cardiac CT examinations should demonstrate evidence of continuing competence in the interpretation and reporting of those examinations. If competence is assured primarily on the basis of continuing experience, a minimum of 75 examinations, excluding those performed exclusively for calcium scoring, every 3 years is recommended in order to maintain the radiologist's skills.

Continuing medical education.—The radiologist's continuing medical education should be in accordance with the "ACR Practice Guideline for Continuing Medical Education (CME)" of 150 hours of approved education every 3 years, and should include continuing medical education in general and in cardiac CT as is appropriate to the radiologist's practice needs.

The Technologist

Technologists performing CT examinations should be certified by the American Registry of Radiologic Technologists (ARRT) or have an unrestricted state license with documented training and experience in cardiac imaging procedures. It is recommended that the technologist performing cardiac CT have advanced certification in CT. Each technologist should have supervised experience in the performance of cardiac CT examinations and in the intravenous administration of conventional CT contrast agents. If intravenous contrast material is to be administered, qualifications for technologists performing intravenous injections should be in compliance with current ACR policy statements and existing operating procedures or manuals at the imaging facility. (See the "ACR Practice Guideline for the Use of Intravascular Contrast Media." The American College of Radiology approves of the injection of contrast material and diagnostic levels of radiopharmaceuticals by certified and/or licensed radiologic technologists and radiologic nurses under the direction of a radiologist or his or her physician-designee who is personally and immediately available, if the practice is in compliance with institutional and state regulations. There must be prior written approval by the medical director of the radiology department or service of such individuals, such approval process having followed established policies and procedures, and the radiologic technologists and radiologic nurses who have been so approved maintain documentation of continuing medical education related to the materials being injected and to the procedures being performed [resolution 1-H; 1987, 1997].) In addition, each technologist should maintain 24 hours of continuing education every 2 years, as stipulated by the ARRT. It is recommended that these credits include those from activities providing education in the performance of cardiac CT. It is also recommended that technologists performing cardiac CT examinations maintain basic life support certification and be capable of using an automatic external defibrillator.

The technologist should also perform the regular quality control testing of the CT system, with the supervision of a medical physicist.

To ensure competence, all technologists must be evaluated by the supervising radiologist.

Cardiac CT Safety Issues

Safety issues in cardiac CT relate to radiation exposure, IV contrast material administration, and β-blocker and nitrate administration.

With regard to radiation exposure, the supervising physician should be familiar with the various technical parameters of the examination that affect radiation dosage, including milliampere-seconds (mAs) and peak voltage settings (kVp) and scan pitch. Moreover, automated x-ray dose-shaping algorithms and x-ray tube pulsing, when available, should be applied to minimize radiation exposure while allowing diagnostic image quality. As with all examinations that use ionizing radiation, cardiac CT should be performed with a radiation dose that is as low as reasonably achievable, or ALARA, without compromise to the resulting images. This is especially important for cardiac CT patients, since they may undergo many radiographic examinations, including fluoroscopically guided interventional cardiac procedures that may require a high radiation dose. Particular attention to radiation dose is needed for children and young adults, who are more susceptible to the effects of radiation, and especially for young female patients, since the breasts will likely be within the area of scanning. As a general rule a multi–detector CT scan encompassing the heart should not result in a volume CT dose index (CTDI) greater than 60 mGy or an effective dose of greater than 13 mSv (18,19).

With regard to the administration of IV contrast media, the physician should supervise patient selection to identify those patients for whom IV contrast media may present an increased risk or be contraindicated, particularly in those patients with renal insufficiency and/or a history of reaction to contrast media. Some of these patients may require pretreatment to allow safe contrast agent administration. The physician should also be available to treat adverse reactions to IV contrast media. The *ACR Practice Guideline for the Use of Intravascular Contrast Media* (20) and the *ACR Manual on Contrast Media* (21) are helpful resources in this area.

β-Blockers and nitrates are commonly used in conjunction with cardiac CT studies. Physicians performing cardiac CT should be knowledgeable about the administration, risks, and contraindications of these drugs. Blood pressure and heart rate should be monitored.

Cardiac CT Equipment Recommendations

The availability of a multi–detector row helical CT or an electron-beam CT scanner is a requirement for cardiac CT applications, especially for coronary artery calcium scoring and CT angiography. For multi–detector row CT, at least four detector rows are preferred for calcium scoring and at least 16 are preferred for CT coronary angiography. The temporal imaging capability should be 500 msec or less, and spatial resolution should be such that in-plane voxels that approach 0.5 mm^3 are obtainable. The capability to image a section thickness of less than 1.0–1.5 mm is also necessary for coronary imaging, as is electrocardiographic gating and the ability to acquire images in both prospective and retrospective modes.

A powered contrast medium injector that allows programming of both the volume and flow rate of the contrast agent must be used for many contrast medium–enhanced cardiac CT examinations.

A workstation capable of creating multiplanar reformations, maximum intensity projections, and volume renderings or shaded surface displays should be available.

CARDIAC MR IMAGING

Introduction

Clinical application.—Cardiac MR imaging represents the specialized application of MR to imaging the heart to help diagnose both acquired and congenital disease. Applications of cardiac MR include, but are not limited to, the following (36–49): *(a)* assessment of myocardial scar, infiltrative processes, and inflammation; *(b)* assessment of myocardial ischemia; *(c)* assessment of ventricular function; *(d)* characterization of cardiac chamber morphology and function; *(e)* detection and characterization of congenital heart disease; *(f)* characterization of cardiac masses; *(g)* diagnosis of pericardial disease; *(h)* quantification of valvular disease and shunt physiology; *(i)* detection of coronary artery atherosclerosis; *(j)* detection and characterization of coronary artery anomalies; and *(k)* detection and characterization of coronary artery aneurysms.

Technical specifications.—A physician who performs cardiac MR should be familiar with all aspects of the MR examination. This includes not only clinical indications, but also technical specifications. This should include a thorough knowledge of cardiac MR pulse sequences, which include (but are not limited to) gradient-recalled-echo sequences including steady-state balanced methods (fast imaging with steady-state precession, or true FISP; fast imaging employing steady-state acquisition, or FIESTA; balanced fast field echo), fast spin-echo and half-Fourier spin-echo sequences, phase-contrast and flow-quantification methods, and contrast-enhanced MR angiography techniques (39,41,43,50–55). The cardiac MR physician should also have a background in MR physics as related to cardiac MR to include MR parameters, artifacts, k-space, and image formation, along with knowledge of hardware components such as electrocardiography leads, methods of gating, and basic coil function and design. MR physics training is part of the core curriculum of the radiology residency, and completion of the radiology residency is accepted as evidence of MR physics training.

Qualifications of Personnel

The Radiologist

The radiologist who supervises and interprets cardiac MR examinations should meet the following criteria for cardiac MR:

1. Certification in radiology or diagnostic radiology by the American Board of Radiology, the American Osteopathic Board of Radiology, the Royal College of Physicians and Surgeons of Canada, or Le College des Medecins du Quebec and have supervised and interpreted 75 cardiac MR cases in the past 36 months.

OR

Completed an ACGME-approved radiology residency program and have super-

vised and interpreted 75 cardiac MR cases in the past 36 months.
AND

2. Completed at least 40 hours of category I continuing medical education in cardiac imaging, including cardiac MR, anatomy, physiology, and/or pathology, or have documented equivalent supervised experience in a center where cardiac MR is actively performed.

For pharmacologic stress testing, the radiologist should meet the following criteria:

Radiologists performing pharmacologic stress testing as part of cardiac MR imaging should be knowledgeable about the administration, risks, and contraindications of pharmacologic agents used for stress testing.

Personnel monitoring stress-induced studies should have current advanced cardiac life support certification.

Maintenance of competence.—All radiologists who perform cardiac MR should demonstrate evidence of continuing competence in the interpretation and reporting of those examinations. If competence is assured primarily on the basis of continuing experience, a minimum of 75 examinations every 3 years is recommended in order to maintain the radiologist's skills.

Continuing medical education.—The radiologist's continuing medical education should be in accordance with the "ACR Practice Guideline for Continuing Medical Education (CME)" of 150 hours of approved education every 3 years and should include education in general and cardiac MR as appropriate to the radiologist's practice needs.

The Technologist

The technologist who performs cardiac MR should be certified by the ARRT or have an unrestricted state license with documented training and experience in cardiac imaging procedures. It is recommended that the technologist performing cardiac MR have advanced certification in MR. Each technologist should have supervised experience in the performance of cardiac MR and in the IV administration of conventional MR contrast agents. If IV contrast material is to be administered, qualifications for technologists who performing such injections should be in compliance with current ACR policy statements (20,21) and existing operating procedures or manuals at the imaging facility. (See the ACR Practice Guideline for the Use of Intravascular Contrast Media. The American College of Radiology approves of the injection of contrast material and diagnostic levels of radiopharmaceuticals by certified and/or licensed radiologic technologists and radiologic nurses under the direction of a radiologist or his or her physician-designee who is personally and immediately available, if the practice is in compliance with institutional and state regulations. There must be prior written approval by the medical director of the radiology department or service of such individuals, such approval process having followed established policies and procedures, and the radiologic technologists and radiologic nurses who have been so approved maintain documentation of continuing medical education related to the materials being injected and to the procedures being performed [resolution 1-H; 1987, 1997].) In addition, each technologist should maintain 24 hours of continuing education every 2 years, as stipulated by the ARRT. It is recommended that these credits include those from activities that provide education in the performance of cardiac MR. It is also recommended that technologists performing CMR examinations maintain basic life support certification and be capable of using an automatic external defibrillator.

To ensure competence, all technologists must be evaluated by the supervising radiologist.

Cardiac MR Safety Issues

The cardiac MR physician should have thorough knowledge of patient safety to include specific-absorption-rate, or SAR, limits, possible neurologic effects, tissue heat deposition, and contraindications to MR imaging, such as implantable devices (56).

With regard to the administration of IV contrast media, the physician should supervise patient selection to identify those patients for whom IV contrast medium administration may present an increased risk or be contraindicated. Although contrast agent reactions occur less frequently with gadolinium-based contrast agents than with iodinated agents, some patients may require pretreatment to allow safe contrast medium administration. The physician should also be available to treat adverse reactions to IV contrast media. The "ACR Practice Guideline for the Use of Intravascular Contrast Media" (20) and the *ACR Manual on Contrast Media* (21) are helpful resources in this area.

Cardiac MR Equipment Recommendations

Imagers for clinical cardiac MR should be accredited by the ACR, with equipment performance monitoring in accordance with the *ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of MR imaging Equipment* (57). It is recommended that imagers used for cardiac MR performance have a field strength of 1.0 T or higher and a slew rate of at least 70 mT/m/sec. Also MR imagers need to be equipped with a localized multichannel radiofrequency surface coil and electrocardiographic gating. An MR-compatible power injector is recommended for contrast-enhanced studies. The MR imager should be capable of fast three-dimensional gradient-echo imaging, steady-state imaging with free precession, phase-contrast flow quantification, fast multisection myocardial perfusion imaging, and delayed contrast-enhanced myocardial imaging. Commercial Food and Drug Administration–approved software for data processing (calculation of ejection fractions, reformatting of angiographic data) should be available either as part of the MR system or on a separate workstation. Postprocessing performed by a technologist should be supervised by the cardiac MR physician.

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