ensure the appropriateness of the study and that the potential benefits outweigh the risks. The likelihood that the study being considered will affect clinical management of the patient should be addressed before testing is performed. It is also important that "routine" follow-up scans in asymptomatic individuals be avoided.

CONTRAST AGENTS

Contrast agents are commonly used in cardiac CT, CMR, and echocardiography. Although their use significantly enhances the diagnostic information of each of these tests, there are also potential risks from the administration of contrast agents that should be considered.

The risk of adverse reactions from iodinated contrast agents used in cardiac CT is well established. The precise pathogenesis of contrast reactions following intravascular administration of iodinated contrast media is not known. The overall incidence of contrast reactions is 0.4–3% with nonionic formulations and higher for ionic formulations. Most contrast adverse reactions are mild and self-limiting. The risk of contrast-induced nephropathy (CIN) in patients with relatively normal renal function (glomerular filtration rate [GFR] >60 mL/min) is low. In most patients, CIN is self-limited, and renal function usually returns to baseline within 7–10 days, without progressing to chronic renal failure. However, this risk increases in patients with GFR <60 mL/min, especially older diabetic subjects. In such patients, appropriate screening and pre- and postscan hydration are necessary.

The use of gadolinium-based contrast agents (GBCAs) in CMR imaging enhances the versatility of this technique. Although there are several commercially available GBCAs in the United States, their use in cardiac imaging is considered off-label. Mild reactions from GBCAs occur in ~1% of patients, but severe or anaphylactic reactions are very rare. All GBCAs are chelated to make the compounds nontoxic and to allow renal excretion. Exposure to the nonchelated component of GBCA (Gd3+) has been associated with a rare condition known as nephrogenic systemic fibrosis (NSF), which is an interstitial inflammatory reaction that leads to severe skin induration, contracture of the extremities, fibrosis of internal organs, and even death. Risk factors to developing NSF include high-dose (>0.1 mmol/kg) GBCA use in presence of severe renal dysfunction (estimated GFR [eGFR] <30 mL/min per 1.73 m^2), need for hemodialysis, an eGFR <15 mL/min per 1.73 m^2, use of gadodiamine contrast agent, acute renal failure, acute systemic illness, and presence of concurrent proinflammatory events. With the use of weight-based dosing and pretest screening, recent data suggest that NSF is extremely rare. Previously, an incidence of 0.02% in 83,121 patients exposed to GBCA over 10 years was noted; however, with current eGFR screening guidelines that have been widely practiced since 2006, a near-zero incidence of NSF has been reported.

Contrast agents can also be used in echocardiography. Injected agitated saline is used routinely to assess cardiac shunts, because these "bubbles" are too large to traverse the pulmonary circulation. After saline injection, the presence of bubbles in the left side of the heart is indicative of shunt, although the location can sometimes be difficult to determine. Dedicated echocardiographic contrast agents have been developed for opacification of left-sided structures and perfusion, although these are only currently U.S. Food and Drug Administration (FDA) approved for perfusion. These agents are either albumin- or lipid-based microspheres filled with inert gases, typically perfluorocarbons. They are considered extremely safe, although they have, in extremely rare instances, been associated with allergic reactions and neurologic events.

SAFETY CONSIDERATIONS OF CMR IN PATIENTS WITH PACEMAKERS AND DEFIBRILLATORS

The risks of performing CMR in the presence of a pacemaker include generation of electrical current from the metallic hardware (especially if wire loops exist), device movement induced by the magnetic field, inappropriate pacing and sensing, and heating as a result of the "antenna's effect." While the presence of a permanent pacemaker remains a contraindication to CMR, highly experienced centers had reported success in performing MRI in these patients in a carefully monitored clinical setting. In general, patients need to be not pacemaker-dependent, the setting of the pacemaker needs to be modified to aysnchronous mode, and the pulse sequence needs to be modified to reduce the amount of radiofrequency energy deposition. Pacemakers implantated for less than 6 weeks and the presence of epicardial, abandoned, or nonfixation leads are considered unsafe. Collectively, evidence from combined reports of >250 patients with pacemaker models manufactured after year 2000 suggests that CMR at 1.5 T or less can be performed without significant risk for the patient and with minor nonpermanent alteration of pacemaker settings and function. Similar safety data exists for automatic implantable cardioverter-defibrillators (AICDs), but they are based only on small numbers of patients. In 2011, the first CMR-compatible FDA-approved permanent pacemaker became available commercially. Currently, no AICD has achieved FDA clearance for MRI compatibility.

PATIENT-CENTERED APPLICATIONS OF CARDIAC IMAGING

CORONARY ARTERY DISEASE

The basis for the diagnostic application of imaging tests in patients with known or suspected CAD should be viewed in light of the pretest probability of disease as well as the specific characteristics of imaging tests (i.e., sensitivity and specificity). In symptomatic patients, the prevalence or pretest probability of CAD differs based on the type of symptom (typical angina, atypical angina, noncardiac chest pain), as well as on age, gender, and coronary risk factors. In an individual patient, the results of the initial test informs the posttest likelihood of CAD. In patients undergoing sequential testing (e.g., ECG treadmill testing followed by stress imaging), the posttest probability of disease after the first test becomes the pretest likelihood of disease for the second test. Regardless of the sequence, the expectation is that a test will provide sufficient information to confirm or exclude the diagnosis of CAD and that such information will allow accurate risk stratification to be able to guide management decisions.

Table 270e-3 summarizes the relative diagnostic accuracies of cardiac imaging modalities for the diagnosis of CAD.

It is important to highlight that the vast majority of studies included in meta-analyses of the diagnostic accuracy of cardiac imaging modalities for the diagnosis of CAD were retrospective, small, single-center studies, comprising predominantly male patients with a high prevalence

TABLE 270e-3 COMPARATIVE DIAGNOSTIC ACCURACY OF CARDIAC IMAGING APPROACHES TO CORONARY ARTERY DISEASE

Imaging Modality	Published Data	Sensitivity	Specificity
Exercise echocardiography	15 studies (n = 1849 patients)	84%	82%
Dobutamine echocardiography	28 studies (n = 2246 patients)	80%	84%
SPECT MPI	113 studies (n = 11,212 patients)	88%	76%
Myocardial perfusion PET	9 studies (n = 650 patients)	93%	81%
CMR perfusion	37 studies (n = 2841 patients)	91%	81%
CMR wall motion	14 studies (n = 754 patients)	83%	86%
Coronary CTA	18 studies (n = 1286 patients)	99%	89%

Note: In these studies, the diagnosis of coronary artery disease was based on the presence of a >50% or >70% stenosis on invasive coronary angiography.

Abbreviations: CMR, cardiac magnetic resonance; CTA, computed tomography angiography; MPI, myocardial perfusion imaging; PET, positron emission tomography; SPECT, single-photon emission computed tomography.