Cardiac Magnetic Resonance Imaging: Choice of the Year
– Which Imaging Modality Is Best for Evaluation of Myocardial Ischemia? (MRI-Side) –
Stephen CW Cheung; Carmen WS Chan

The increasing variety of available cardiac imaging techniques have made the investigation of coronary artery disease more complex. On the one hand, nuclear cardiology or myocardial perfusion imaging (MPI) allows accurate and reliable quantitative measurement of myocardial blood flow. On the other hand, a newer technique, cardiac magnetic resonance imaging (CMR) is an attractive alternative for achieving similar purposes without exposing patients to radiation hazards. With a higher spatial resolution, CMR is more sensitive for detecting subendocardial ischemia; small myocardial infarction and/or fibrosis, which cannot be achieved in a nuclear study. Nuclear MPI has dominated clinical practice over the past 3 decades on the basis of an extensive amount of research. More upcoming research on CMR would warrant more evidence-based data of its value for disease diagnosis, prognosis and risk stratification and incorporating it into the clinical diagnostic and management algorithm. (Circ J 2011; 75: 724–731)

Key Words: Cardiac magnetic resonance imaging; Myocardial ischemia; Stress myocardial perfusion

Over the past decade, there has been a great technical innovation in imaging of the heart and the coronary arteries. Newer magnetic resonance (MR) scanners allow assessment of myocardial contraction, myocardial thickness, measurement of chamber size, myocardial flow and myocardial viability in one examination without exposing the patient to any radiation (Figure). Meanwhile, the application of nuclear myocardial perfusion and viability studies in patients with coronary artery disease (CAD) has dominated the past 30 years, supported by abundant prognostic reports. Both techniques can detect low-risk and high-risk subsets among patients with known or suspected CAD. They have been used to identify the presence of residual ischemic but viable myocardium and thereby predict the functional recovery in patients with acute myocardial infarction (MI). Similarly, in patients with chronic ischemic left ventricular dysfunction, viability assessment with either modality can be used to predict improved function after revascularization and thus guide patient management. However, the truth is each of these techniques has its own inherent limitations and strengths (Table 1). Since CAD accounts for a huge patient population and has a great economic impact on both the social and medical aspects, it is time to once again address the question “What is the optimal noninvasive cardiac imaging method?”.

Diagnostic Performance of Stress Perfusion Cardiac MR Imaging (CMR)

It is well shown that stress myocardial perfusion imaging (MPI) is important in the assessment of patients with CAD, because the degree of morphological narrowing of the coronary artery does not correlate well with the functional significance of the CAD lesion. First-pass contrast-enhanced MR imaging of the myocardium with pharmacological stress has been shown to provide an accurate assessment of myocardial ischemia caused by flow-limiting stenosis. ECG-gated dynamic MR images are acquired using different imaging sequences to monitor the first-pass dynamics of the contrast medium through the LV myocardium. Ischemic myocardium resulting from reduced myocardial blood flow is visualized as an area exhibiting slower flow and hypo-enhancement compared with normal myocardium on stress perfusion MR imaging. The operating characteristics of CMR stress perfusion studies are good and comparable to other stress imaging modalities. In a recently reported meta-analysis, a pool of 35 original articles fulfilling the inclusion criteria were included. Among the 2,456 patients (68.7% male; mean age 61.3 years) from 26 patient-based analyses, the analyzed data demonstrated that the CMR perfusion study had a sensitivity of 89% (95% confidence interval (CI) 88–91%), a specificity of 80% (95%CI: 78–83%), a positive likelihood ratio (PLR) of 4.18 (3.31–5.27), a negative likelihood ratio (NLR) of 0.15.
(95% CI: 0.11–0.20), a diagnostic odd ratio (DOR) of 33.65 (95% CI: 22.09–51.27), and an area under the curve (AUC) of 0.92. Moreover, stress perfusion CMR with adenosine had a better sensitivity than that with dipyridamole (90 (88–92%) vs. 86% (80–90%), P=0.022), and a tendency toward better specificity (81% (78–84%) vs. 77% (71–82%), P=0.065). A sensitivity analysis was also carried out based on the magnetic field strength of scanners used in this meta-analysis study. For the 23 studies (1,904 patients) performed by 1.5 Tesla scanners, the sensitivity was 89% (87–91%), specificity of 80% (78–83%), PLR of 4.26 (3.26–5.55), NLR of 0.15 (0.11–0.20) and DOR of 34.25 (21.26–55.17). However, only 4 studies were conducted using 3 Tesla MR scanners. The result showed that there is a higher sensitivity of 92% (87–95%) and similar specificity of 78% (69–85%), respectively.

There were in total 2,709 coronary territories pooled from 17 studies. Regarding the per-territory analysis, there was a significant heterogeneity effect on all diagnostic performance except sensitivity, NLR and DOR. The results revealed a sensitivity of 82% (79–84%), specificity of 84% (82–85%), PLR of 4.90 (3.66–6.55), NLR of 0.23 (0.20–0.27), and DOR of 23.23 (18.33–29.45). Only 8 datasets were available for per-artery analysis. The demonstrated sensitivity and specificity for the left anterior descending artery were 82% (79–84%) and 84% (82–85%), respectively.

Table 1. Comparison of the Technical Aspects of MRI, SPECT and PET

<table>
<thead>
<tr>
<th></th>
<th>MRI</th>
<th>SPECT</th>
<th>PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation exposure</td>
<td>None*</td>
<td>Sestamibi (1 day) stress/rest 9 mSv, Technetium-99m 8–12 mSv, Thallium stress/rest 14–21 mSv</td>
<td>F-18 FDG 14 mSv, Rubidium-82 5 mSv</td>
</tr>
<tr>
<td>Pretest preparation</td>
<td>Check GFR or, if ESRF, schedule dialysis after MRI</td>
<td>Prepare radioactive isotopes</td>
<td>Order isotopes from cyclotron</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-y plane</td>
<td>1.5–2 mm*</td>
<td>11–17 mm</td>
<td>7–12 mm</td>
</tr>
<tr>
<td>z axis</td>
<td>8–12 mm, anisotropic*</td>
<td>11–17 mm</td>
<td>7–12 mm, isotopic</td>
</tr>
<tr>
<td>Impact of arrhythmia</td>
<td>Cardiac gating problem, impedes image quality</td>
<td>No effect on basic image*</td>
<td>No effect on basic image*</td>
</tr>
<tr>
<td>Breath-holding</td>
<td>Essential for optimal image quality</td>
<td>Not needed*</td>
<td>Not needed*</td>
</tr>
<tr>
<td>Scanning time</td>
<td>45–60 min for a complete examination: cardiac function, rest &amp; stress perfusion and viability study*</td>
<td>1 or 2 day protocol</td>
<td>2–3 h, 20–35 min in the camera</td>
</tr>
<tr>
<td>Claustrophobia issues</td>
<td>Infrequent but more commonly encountered than nuclear study</td>
<td>Occasional*</td>
<td>Occasional*</td>
</tr>
<tr>
<td>Pacemaker, ICD issues</td>
<td>Contraindicated</td>
<td>No problem but the pacing sites may affect diagnostic accuracy*</td>
<td>No problem*</td>
</tr>
<tr>
<td>Renal insufficiency or ESRF</td>
<td>Contraindicated (ARF or HRS)</td>
<td>No problem*</td>
<td>No problem*</td>
</tr>
<tr>
<td>Initial costs</td>
<td>Moderate*</td>
<td>Large but less expensive than PET</td>
<td>Large</td>
</tr>
</tbody>
</table>

*The superior parameters among the 3 imaging modalities.

MRI, magnetic resonance imaging; SPECT, single-photon-emission computed tomography; PET, positron emission tomography; FDG, fluorodeoxyglucose; GFR, glomerular filtration rate; ESRF, endstage renal failure; ICD, implantable cardioverter defibrillator; ARF, acute renal failure.
artery (LAD), circumflex artery (LCX) and right coronary artery (RCA) was 83%, 76%, and 78% and 83%, 87%, and 87%, respectively. Similarly, the heterogeneity was observed for all the performance measurements except sensitivity and NLR for the LAD and LCX, and DOR for the LCX.

It must be noted that there is heterogeneity among the imaging protocols, concentration of gadolinium, stress agents, and imaging sequences from different centers in the above-mentioned studies. Therefore, the MR-IMPACT study (a double-blind, randomized, multicenter and multivendor trial) was conducted to determine the diagnostic performance of MR perfusion imaging in comparison with coronary X-ray angiography and single-photon emission computed tomography (SPECT). It demonstrated a sensitivity of 0.85 and specificity of 0.67 (AUC 0.86±0.06), comparing favorably with SPECT (AUC 0.75±0.09).

Myocardial perfusion MR imaging can be evaluated by visual analysis, semiquantitative analysis or quantitative analysis. Quantitative analysis of myocardial blood flow and myocardial perfusion reserve allows an objective evaluation of myocardial ischemia and microvascular disease. More recently, MR perfusion imaging has been validated against invasive assessment of coronary blood flow, notably fractional flow reserve (FFR). Even qualitative assessment of stress perfusion CMR accurately reflected the findings on FFR in 103 patients, among whom 58% has significant CAD, with positive (PPV) and negative (NPV) predictive values for FFR ≤0.75 of 90.9% and 93.9%, respectively.14

**Specific Patient Groups**

**Detection of CAD in Women** Noninvasive diagnostic testing for women presenting with chest pain symptoms or angina remains a challenge. The specificities in published meta-analyses for exercise ECG, stress echocardiography and stress SPECT in women are only 70%, 73–79% and 64–69%, respectively. The accuracy is most likely hampered by the lower prevalence of CAD, more frequent single-vessel disease, more intermediate grade stenosis and smaller heart in women. By combined CMR stress protocol and defining CAD as stenosis ≥70% on quantitative analysis of coronary angiography (CAG), a sensitivity of 84%, specificity of 88% and accuracy of 87% was reported by Klem et al in 136 women with suspected CAD (prevalence of CAD 27%). The specificity of stress CMR is highly favorable compared with that of the other stress tests mentioned above. The high negative predictive value (94%) have a great impact on healthcare expenses.

**Detection of Triple-Vessel CAD** The accuracy of SPECT in detecting triple-vessel disease is low despite an excellent overall sensitivity for CAD in previous studies. In the study performed by Martin et al, 20% of patients with triple-vessel CAD have normal thallium scan.17

### Table 2. Summary of Prognostic Stress CMR Studies

<table>
<thead>
<tr>
<th>Patient population</th>
<th>Stress agent</th>
<th>All events</th>
<th>Hard events (cardiac death/MI)</th>
<th>Mean follow-up (years)</th>
<th>Hard events/year</th>
<th>HR</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dall’Armellina et al27</td>
<td>200</td>
<td>LVEF &lt;55%, rest WM &amp; suboptimal echo</td>
<td>Dobutamine WM</td>
<td>35</td>
<td>35</td>
<td>5</td>
<td>3.5%</td>
</tr>
<tr>
<td>Jahnke et al26</td>
<td>513</td>
<td>Suspected or known CAD, prior CABG or PCI</td>
<td>Adenosine perfusion and dobutamine WM</td>
<td>19</td>
<td>19</td>
<td>2.3</td>
<td>1.6%</td>
</tr>
<tr>
<td>Bodi et al29</td>
<td>420</td>
<td>Suspected or known CAD</td>
<td>Dipyridamole perfusion</td>
<td>41</td>
<td>23</td>
<td>1.2</td>
<td>4.6%</td>
</tr>
<tr>
<td>Steel et al31</td>
<td>254</td>
<td>Symptoms of myocardial ischemia</td>
<td>Adenosine perfusion + LGE</td>
<td>49</td>
<td>28</td>
<td>1.4</td>
<td>7.9%</td>
</tr>
<tr>
<td>Doesch et al32</td>
<td>81</td>
<td>Intermediate stenosis</td>
<td>Adenosine perfusion</td>
<td>44</td>
<td>9</td>
<td>2.5±0.67</td>
<td>4.4%</td>
</tr>
<tr>
<td>Wallace et al33</td>
<td>266</td>
<td>Women subgroup</td>
<td>Dobutamine WM</td>
<td>149</td>
<td>36</td>
<td>6.2±1.6</td>
<td>2.1%</td>
</tr>
<tr>
<td>Bodi et al34</td>
<td>214</td>
<td>STEMI</td>
<td>Dobutamine WM</td>
<td>69</td>
<td>35</td>
<td>1.5 (0.8–2.8)</td>
<td>9.7%</td>
</tr>
<tr>
<td>Korosoglou et al35</td>
<td>1,493</td>
<td>Suspected or known CAD</td>
<td>Dobutamine WM and perfusion</td>
<td>138</td>
<td>53</td>
<td>2±1</td>
<td>1.8%</td>
</tr>
<tr>
<td>Lerakis et al36</td>
<td>103</td>
<td>Chest pain without ECG and cardiac markers evidence of MI</td>
<td>Adenosine perfusion</td>
<td>1</td>
<td>0</td>
<td>0.8 (0.4–1.3)</td>
<td>0%</td>
</tr>
</tbody>
</table>

*Adjusted to risk factors and prior MI.
CMR, cardiac magnetic resonance imaging; MI, myocardial infarction; all events, all primary and secondary endpoints; LVEF, left ventricular ejection fraction; WMA, wall motion abnormalities; dobutamine WM, dobutamine wall motion assessment; CAD, coronary artery disease; CABG, coronary artery bypass grafting; PCI, percutaneous coronary intervention; LGE, late gadolinium enhancement; NC, not calculated; STEMI, ST-segment elevation myocardial infarction; NS, not significant.
capable of detecting only 49% patients with left main artery and multivessel disease. In the largest study, which consists of 78 patients with angiographically proven triple-vessel CAD, the diagnostic performance of CMR stress perfusion was compared with SPECT. It showed that significantly more myocardial ischemia was detected by stress CMR perfusion than by SPECT (84.6% vs. 55.1%, P<0.001 in 3 vascular territories; 100% vs. 96.2% per patient). The overall perfusion defects in all 3 vascular territories were detected in 57.7% of patients by stress perfusion MR imaging, but in only 11.5% of patients by SPECT. Probably the superiority of CMR perfusion in detecting balanced ischemia and subendocardial ischemia is accounted for by its higher spatial resolution.

**Patients With Aortic Disease** There is a high incidence of significant CAD in patients suffering from aortic aneurysm. The complication risk, such as distal embolization, is obviously higher for performing conventional CAG. The interpretation of computed tomography (CT) CAG may not be feasible with heavy coronary artery calcification. Ishida et al have reported that CMR stress perfusion combined with late gadolinium enhancement (LGE) is useful for detecting CAD in this patient group prior to elective repair of aortic aneurysm, with sensitivity, specificity and accuracy of 88%, 87% and 88%, respectively, using conventional CAG as a reference.

**Diagnostic Performance for Myocardial Contraction**

Cine MR imaging has become the standard method for evaluating the morphology and function of the heart. The excellence in delineation of the blood pool and endocardial border, and the unlimited imaging planes make it a very useful tool for the clinical workup and management of CAD patients. The sensitivity and specificity for significant CAD detection ranges from 78% to 89% and from 75% to 88%, respectively, in the reported literature. Besides, by using myocardial tagging MR imaging, altered regional wall motion and myocardial strain during dobutamine stress also can be accurately and objectively assessed in patients with myocardial ischemia or ischemic cardiomyopathy.

**Prognostic Role of CMR Perfusion in CAD Patients: Emerging Data**

With CMR stress perfusion studies more established, data demonstrating its prognostic value are accumulating. Patients with CMR MPI defects have a worse prognosis for hard events (1.6–9.7% per year with moderate to severe defects) (Table 2). Earlier study by Jahnome et al showed that in 461 patients with known or suspected CAD, the presence of myocardial ischemia detected by combined adenosine perfusion and dobutamine-induced abnormal wall motion is an independent predictor for future cardiac death or nonfatal MI. The event rate at 3 years was 16.3% for patients with abnormal stress MPI (hazard ratio 12.5, 95%CI 3.64–43.03). In contrast, a normal CMR perfusion study was associated with a low event rate (<1% per year) and the 3-year event-free survival was 99%. This favorably compared with the prognosis reported for a normal SPECT scan. Similar prognostic results were demonstrated in a group of stable angina patients with intermediate coronary artery stenoses (defined as 50–75% stenosis on CAG). At the mean follow-up period of 30±8 months, major adverse cardiac events (MACE) had occurred only in patients (n=9) with an identified perfusion defect (P=0.014). Among the patients who experienced MACE, the number of ischemic segments was significantly higher (2.3±1.6 vs. 1.4±1.6, P=0.0025), whereas the frequency of delayed enhancement segments did not differ. Besides, more frequent target vessel revascularization occurred in patients with a perfusion defect compared with those without a perfusion defect on stress MR (38% vs. 6% respectively, P=0.005).

**MRA of Coronary Arteries**

CMR allows direct visualization of the coronary arteries and assessment of myocardial ischemia at the anatomical level. It can be performed solely or be part of the workup for CAD, apart from a MPI study. An early multicenter study evaluated the diagnostic accuracy of free-breathing 3D gradient echo coronary MRA, and the sensitivity and specificity were reported as 93% and 42%, respectively, for detecting patients with significant CAD, and 100% and 85%, respectively, for predicting patients with left main CAD and triple-vessel diseases. Unfortunately, the method for acquisition of images took a long time and only a portion of the coronary arteries was imaged. More recent studies using whole-heart coronary MRA imaging have been performed. It enables reduced scanning time and better image quality even without contrast injection. The overall sensitivity is reported to be around 78% and specificity 91–96% from different centers. Though CMR MRA is far less popular than CT CAG (CTA) as a non-invasive means of anatomical detection of CAD due to longer scanning time and inferior spatial resolution, the freedom from radiation and the satisfactory diagnostic performance for proximal coronary artery segments without the need for contrast injection makes it an ideal imaging method for Kawasaki disease patients with coronary artery aneurysms and for assessment of anomalous coronary arteries.

**Performance for Myocardial Viability Assessment**

LGE MR imaging has been increasingly used for assessing myocardial viability in patients with acute or chronic MI. Table 3 shows the clinical efficacies of MR imaging and nuclear imaging for assessing myocardial viability. The high spatial resolution of MR imaging allows visualization of small subendocardial MI that are missed by SPECT. In a study of 91 patients with suspected or known CAD, MR imaging identified 92% of segments (100 of 109 segments) with a subendocardial infarction whereas SPECT identified only 28% (31 segments). On a per patient basis, 13% (6 patients) with subendocardial infarcts were missed by SPECT but identified by MR. Kühl et al directly compared MR imaging and positron emission tomography (PET)/SPECT in 29 patients with ischemic cardiomyopathy. The PPV was identical for both techniques (73%) but MR imaging had a more favorable NPV (93% vs. 77%). Besides, MR imaging has shown its...
superiority to PET in assessing myocardial viability in thinned myocardial segments. Due to the partial volume effect, significant thinning of viable myocardium reduces the apparent regional fluorodeoxyglucose uptake, resulting in a false-negative PET finding. The diagnostic accuracy of MR imaging is unaffected in these circumstances. However, the prediction of functional recovery as assessed by quantification of the transmural extent of LGE (ie, scar) creates “shades of grey” in clinical interpretation. Patterson et al.44 reinterpreted the results of the paper by Kim et al.45 and reported contrast-enhanced MR imaging is diagnostic in only 64% of segments. In nontransmural scars (1–74%), only an intermediate likelihood of functional recovery after revascularization (62% in LGE transmurality <25% to 7% in LGE transmurality of 50–74%) was found. As the viable myocardium surrounding the scar may be normal, remodeled, hibernating, stunned, or ischemic, LGE MR imaging cannot distinguish and delineate the nature of such myocardium. Low-dose dobutamine stress MR imaging assessing regional wall motion depends on both the function of viable and the extent of nonviable myocardium and has been shown to be superior to LGE MR imaging in predicting functional recovery after revascularization in segments containing LGE of 1–74%.47 However, both techniques have similar efficacy when there are no infarcts. DCMR has also been compared to the metabolic assessment of viability obtained during radionuclide studies. Baer et al reported that implementation of dobutamine stress MR imaging providing more information regarding viability than resting LV end-diastolic wall thickness.48 They compared the end-diastolic wall thickness at rest and dobutamine-induced systolic wall thickening assessed by DCMR with PET, and concluded that DCMR was a better predictor of residual metabolic activity (sensitivity of 81%, specificity of 95%, and PPV of 96%) than PET (sensitivity of 72%, specificity of 89%, and PPV of 91%).

Though LGE MR imaging is still in its infancy with regard to prognostic data compared with nuclear studies, an early study by Kwong et al reported that in patients with suspected CAD who had no prior MI, the presence and extent of myocardial scar detected by LGE MR imaging was a strong predictor of MACE and cardiac death.49 The presence of a myocardial scar was more frequent than expected in their study.

Using LGE MR imaging, a high prevalence of silent MI (28%) in diabetic patients without clinical evidence of MI has been demonstrated. In addition, diabetic patients without clinical evidence of MI, but with MR evidence of infarction, have significantly worse event-free survival compared with patients without MR evidence of MI (P=0.001). Though the mechanism for silent myocardial ischemia is not yet well known and its presence clearly reflects a worse prognosis,50 these recent findings provide insights on the important role of screening for unrecognized myocardial scarring with contrast-enhanced MR imaging and detecting patients at high risk of future cardiovascular events.

### Safety Issues

CMR has the inherent advantages of its noninvasive nature and absence of radiation exposure. However, like any other imaging modality, limitations exist. Patients with unstable conditions who need close hemodynamic monitoring are not suitable for CMR. Morbid obesity is also a limitation due to the relatively small-bore diameter of the magnet. Arrhythmias such as atrial fibrillation may impair image quality and grossly reduce diagnostic accuracy, though it was reported recently that CMR allows risk stratification in patients with frequent ventricular ectopic with left bundle branch block (LBBB) morphology.51 Besides, there are increasing concerns regarding the link between the use of gadolinium-DTPA and nephrogenic systemic fibrosis (NSF) in patients with renal insufficiency.525455 By implementing guidelines restricting the use of gadolinium in patients with impaired renal function, and switching to optimally stable forms of the contrast agent that have been shown to avert the development of NSF in follow-up, CMR perfusion imaging can remain a safe noninvasive imaging technique in the majority of patients. It is well recognized that nuclear perfusion imaging performed in patients with intrinsic or pacemaker-induced LBBB has a high false-positive rate for ischemia detection, but unfortunately, CMR is not yet able to provide the solution, because the greatest safety issue in the clinical application of CMR imaging is patients with pacemakers and implantable defibrillators. Several studies suggest that some patients with pacemakers or defibrillators may be able to undergo MR imaging. Mollerus et al reviewed 75 noncardiac MR imaging scans in 40 patients and found no unanticipated device programming changes, no changes in battery status or capture threshold, and no change in cardiac troponin I or myoglobin values.56 Pulver et al performed cardiac MR imaging in 11 congenital heart disease patients with epicardial pacing leads, and inappropriate pacing or arrhythmia did not occur. Device voltages, thresholds, and lead impedances were similar before and after MR imaging. However, it is notable that the most of the reports in the literature refer to patients with pacemakers undergoing noncardiac MR scans. According to the current

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**Table 3. Comparison of the Clinical Efficacy of MRI and Nuclear Study Imaging (SPECT/PET) for Assessing Myocardial Viability**

<table>
<thead>
<tr>
<th></th>
<th>MRI</th>
<th>SPECT/PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of small subendocardial MI</td>
<td>Higher sensitivity due to higher resolution*</td>
<td>Lower sensitivity</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>93%*</td>
<td>77%</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>73%</td>
<td>73%</td>
</tr>
<tr>
<td>PPV in thinned myocardium</td>
<td>Relatively higher*</td>
<td>Relatively lower</td>
</tr>
<tr>
<td>Prognostic data</td>
<td>Minimal</td>
<td>Abundant*</td>
</tr>
<tr>
<td>Valvular regurgitation evaluation</td>
<td>Possible*</td>
<td>Impossible</td>
</tr>
<tr>
<td>Detection of microvascular obstruction</td>
<td>Possible*</td>
<td>Need to verify, probably corresponds to more severe defects</td>
</tr>
<tr>
<td>Patients with diabetes mellitus</td>
<td>Not limited except in renal insufficiency*</td>
<td>PET is suboptimal in diabetic patients</td>
</tr>
<tr>
<td>Patients with LBBB</td>
<td>No problem*</td>
<td>Can produce false-positive FDG perfusion defect</td>
</tr>
</tbody>
</table>

*The superior parameters.

LBBB, left bundle branch block. Other abbreviations see in Tables 1, 2.
recommendations, an implantable pacemaker or defibrillator is still considered a strong relative contraindication for routine MR examination.28 MR examination of nonpacemaker-dependent patients is discouraged and should only be considered in cases in which there is a strong clinical indication and in which the benefits clearly outweigh the risks. With respect to pacemaker-dependent patients and those with an implantable defibrillator, MR examination should not be performed unless there are highly compelling circumstances and when the benefits clearly outweigh the risks in highly experienced centers in the presence of expertise. When doubt remains as to the MR safety of any biomedical implant and device, consulting dedicated websites (www.MRISafety.com), reference manuals, or the manufacturer's product information when available, is mandatory.

Conclusion

No single imaging modality is without limitations. The different imaging modalities create differences in applicability for different patients. Nevertheless, the primary goal of all cardiovascular imaging is to determine the best testing strategy to answer a particular clinical scenario while minimizing the risks and costs. The "best choice of test" depends on the proper selection of imaging modality and the knowledge of the medical personnel concerned. There is no doubt that with its unique merits CMR has a role in investigating and managing suspected CAD patients.

References

Authors’ Comments on the SPECT-Side Authors

Drs Yoshinaga et al have compiled a very comprehensive review of the state of the art of nuclear myocardial perfusion imaging in the management of patients with suspected or established ischemic heart disease. Myocardial perfusion imaging using \textsuperscript{201}Tl and various \textsuperscript{99m}Tc-labeled compounds has a long history of clinical use. While various imaging techniques (also including MR and CT) yield largely comparable accuracy, MPI with radiopharmaceuticals has the strongest data supporting its value in predicting patient prognosis. PET may further reduce the uncertainty previously encountered, notably in female and obese patients. However, cyclotron availability is limiting the wider use of ammonium. \textsuperscript{82}Rubidium is a generator product but the useful life of the generator (~4–8 weeks) makes it a viable option only if a large number of cardiac patients can be scheduled close together, and in a general nuclear medicine service that has patients from different specialties, this can be a problem. The shortage of radiopharmaceuticals worldwide a couple of years ago has not yet been forgotten. Interrupted production from a facility can seriously affect the global supply, although thallium is cyclotron-produced and therefore less affected. Apart from MR, CT is also a promising new addition to comprehensive cardiac assessment. With the introduction of wide-detector CT, CAG, and perfusion and viability studies can be performed at a radiation dose not much different from that of a nuclear study. Large studies are underway and the results may cast more light on future application.