Clinical Use of Cardiac Magnetic Resonance Imaging
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ABSTRACT

PURPOSE: To review the uses of cardiac magnetic resonance (CMR) imaging in the management of patients with heart disease.

EPIDEMIOLOGY: CMR has applications in the evaluation of congenital heart defects, which are present in more than 1 million adults in the United States; cardiomyopathies, which account for approximately 20% of all sudden deaths in younger adults; and coronary artery disease, which is the single leading cause of death in the United States.

REVIEW SUMMARY: The superior resolution of CMR provides detailed information about cardiac function, chamber volumes, myocardial mass, and valvular function. An additional important property of CMR is its usefulness for assessing the direction and velocity of blood flow. CMR has become the gold standard technique for use in evaluating right ventricular volumes, systolic function, and degree of pulmonary valve regurgitation in patients with tetralogy of Fallot. It also is used often to assess coarctation of the aorta. CMR has become an important component in determining appropriate intervention for atrial septal defects as well as to diagnose and monitor myocarditis, restrictive cardiomyopathy, and hypertrophic obstructive cardiomyopathy. Delayed gadolinium-enhanced CMR images obtained soon after myocardial infarction can distinguish between reversible and irreversible myocardial dysfunction.

TYPE OF AVAILABLE EVIDENCE: Prospective cohort studies, unstructured reviews.
GRADE OF AVAILABLE EVIDENCE: Good.
CONCLUSION: CMR is expected to make increasingly important contributions to the management of patients with cardiovascular defects and disease.

Cardiac magnetic resonance imaging (CMR) is becoming part of the clinical mainstream. A decade ago, CMR primarily was a research tool that clinicians only dreamed about; now, it is becoming a standard clinical service. It is a versatile tool that gives physicians unrestricted access to structures throughout the chest in multiple freely chosen planes or slices.

CMR has multiple applications in the evaluation of nonischemic and ischemic heart disease. Baseline images provide detailed information regarding cardiac function, chamber volumes, myocardial mass, and valvular function. The superior resolution of CMR allows excellent morphologic characterization of congenital heart defects. First-pass perfusion imaging using gadolinium contrast can be performed to identify areas of myocardial ischemia. Additionally,
delayed gadolinium hyperenhancement (DHE) identifies areas of nonviable (infarcted) myocardium in patients with ischemic heart disease, a technique that is becoming increasingly important in the management of these patients. This article provides an overview of the areas in which CMR is being used to improve the management of patients with various forms of heart disease.

**Equipment and Protocol**

The CMR images illustrated in this review were obtained with a Siemens 1.5 Tesla magnet and corresponding imaging software. The images were acquired using a phase-array receiver coil that rests on the anterior chest wall. Electrocardiographic gating allows images to be obtained at specific times during the cardiac cycle.

CMR images can be obtained in most individuals; use is contraindicated in patients with a permanent pacemaker or defibrillator, ferromagnetic cerebral aneurysm clips, metallic objects lodged within the eye, or severe claustrophobia. Use of CMR in patients with most metallic devices and clips implanted in the chest, such as intracoronary stents, is safe provided the devices do not incorporate an electric component.

Gadolinium-based contrast agents are commonly used in CMR imaging, although they are not specifically labeled for this use. The gadolinium ion possesses a powerful magnetic moment. The effect of gadolinium on the CMR image is afforded by its interaction with the tissue hydrogen protons, facilitating and speeding the magnetic relaxation of these protons.

Gadolinium contrast agents are generally well tolerated. Unlike iodinated radiographic contrast agents, gadolinium is not nephrotoxic. Gadolinium contrast can be used to produce detailed angiograms of vascular structures, including the aorta, pulmonary arteries, and pulmonary veins. Once obtained, the image can be rotated and viewed from any plane or perspective of interest.

The recent improvements that have allowed CMR to become a useful clinical tool include enhancements in hardware and software components of the imaging system. Magnets have become more powerful, allowing more rapid image acquisition. The protocols used to acquire and analyze the images continue to improve, providing enhanced tissue resolution. Many of the images shown in this article were obtained via fast imaging with steady-state precession (true-FISP) image sequences, a method that decreases scan time and improves the signal-to-noise ratio of the images. True-FISP cine imaging involves the acquisition of multiple sequential images that are played back in a movielike loop and are useful in the evaluation of cardiac motion and function. Cine sequences corresponding to some of the still images in this review are noted throughout the article and can be viewed with this article online at www.JHASIM.com/journal.

**Congenital Heart Disease**

Congenital cardiovascular defects, the most common congenital malformations in newborns, occur in about 9 per 1000 (1%) live births. Early mortality rates vary considerably according to the type of defect, but the overall early mortality rate declined by nearly 30% between 1991 and 2001. In 2000, it was estimated that almost 1 million US adults had congenital heart disease and that the number would increase by about 5% each year. As this population continues to grow, the management of congenital heart disease is becoming increasingly important and challenging. Limited evidence is available for making the difficult disease-management decisions in these individuals. Additionally, echocardiographic image quality often is suboptimal in adult patients with congenital heart disease, owing to various issues, such as body habitus, coexisting lung disease, and surgical scarring, which limit ultrasound windows and image acquisition. CMR is not adversely influenced by these factors, and thus is becoming an important noninvasive imaging tool in the evaluation and management of patients with congenital heart disease.

**Tetralogy of Fallot**

Tetralogy of Fallot, the most frequent form of cyanotic congenital heart disease, has a prevalence of 0.26 to 0.8 per 1000 live births. It is characterized by obstruction of the right ventricular outflow tract, a ventricular septal defect, an aorta that overrides the right ventricular outflow, and right ventricular hypertrophy. Since the introduction of open-heart surgery for this condition, the 20-year survival rate has improved to nearly 90%; however, the risk of death more than triples during the third postoperative decade, from 0.27% per year to 0.94% per year. The surgical techniques for relieving the right outflow tract obstruction have been modified in recent years in attempts to preserve the integrity of the pulmonary valve; however, many adults who underwent surgery to repair tetralogy of Fallot in childhood are left with severe pulmonary valve regurgitation. Over time, this leads to right ventricular dilation and dysfunction and predisposes these patients to exercise intolerance, atrial and ventricular arrhythmias, and sudden cardiac death.

The timing of pulmonary valve replacement in patients with tetralogy of Fallot remains controversial, partially because of the limited ability to quantify the severity of pulmonary valve dysfunction and to assess right ventricular function. Right ventricular function is difficult to assess using echocardiography because of the complex geometry of the right ventricle and its position in the chest. CMR has become the gold standard for evaluating right ventricular volumes, systolic function, and degree of pulmonary valve regurgitation.
It is used to determine the hemodynamic effects of pulmonary valve replacement in patients with previously repaired tetralogy of Fallot. Figure 1 is a short-axis image of the right and left ventricles in a patient with tetralogy of Fallot. It illustrates the marked right ventricular enlargement that is commonly seen in these patients.

An important property of CMR is its usefulness for assessing the direction and velocity of blood flow. Cine sequence 1 is a true-FISP image taken at the level of the pulmonary outflow tract, just above the pulmonary valve. Note the marked pulsatility of the pulmonary artery, which is characteristic of individuals with pulmonary valve insufficiency. Cine sequence 2 is a velocity-encoded image taken at the same level. Blood flow into the image plane, in this case moving forward into the pulmonary artery, is coded white; blood flow out of the image plane, representing pulmonary regurgitation in this case, is coded black. Using available software, a region of interest can be defined in any image set; the blood velocity in that area can be measured, yielding measurement of blood flow. In this example, the pulmonary artery can be defined as the region of interest to thereby determine the pulmonary artery blood flow.

Figure 2 summarizes these data. At time zero, the beginning of systole, forward flow into the pulmonary artery occurs (coded as positive numbers in mL/sec). During diastole, the flow reverses direction, as illustrated by the zero crossover with flow occurring back into the right ventricle. This negative flow represents pulmonary regurgitation and is coded as negative numbers in mL/sec. This method allows quantification of the regurgitant fraction, which, in this graph, is the area below the zero line that occurs during diastole. In the patient shown in Figure 2, the regurgitant fraction was 40.

These flow-image sequences allow quantification of blood flow in any region of interest in the heart. As another example, the flow in the ascending aorta during the cardiac cycle can be measured. The flow in the ascending aorta multiplied by the heart rate provides a noninvasive measure of cardiac output in L/min.

Patients with tetralogy of Fallot may develop ventricular arrhythmias, which can be life threatening. These arrhythmias often are attributed to prior surgery, which can result in scarring in the right ventricular outflow tract. Preliminary work at our institution using DHE imaging techniques, however, has identified areas of myocardial scarring remote from sites of direct surgical intervention, which may represent substrate for the origin of these ventricular arrhythmias. Figure 3 is a short-axis DHE image of the same individual with tetralogy of Fallot depicted in Figure 1. The bright white areas represent scarring in the anterior and inferior septal insertion sites of the ventricles.
COARCTATION OF THE AORTA

Coarctation (or congenital narrowing) of the aorta accounts for about 5% of all cases of congenital heart disease. The severity of coarctation varies greatly, and some infants who are born with critical coarctation of the aorta require emergency surgery to establish adequate systemic blood flow. Less severe coarctation may be identified during evaluation for hypertension or a murmur. The average life expectancy for patients with untreated coarctation is 31 years; therefore, interventions to alleviate the obstruction are indicated. Patients who have undergone surgical coarctation repair should be followed up throughout their lives, as the incidence of recoarctation may be as high as 35%. Historically assessed by cardiac catheterization and angiography, coarctation of the aorta today is often evaluated with CMR. This technique provides not only anatomic information about the site of coarctation, but also information about the pressure gradient across the stenosis, left ventricular mass and function, aortic valve morphology and function, and the presence and magnitude of collateral vessel flow.

Figure 4 (A and B) and cine sequence 3 show gadolinium-based magnetic resonance angiograms from a patient with aortic coarctation demonstrating the narrowed area in the descending thoracic aorta just distal to the left subclavian artery origin—a typical location for coarctation. These images also show collateral blood vessels (arrows in Figure 4B) around the coarctation site. The volume of blood flow using velocity-encoded imaging is determined both proximal and distal to the coarctation; these measurements provide information regarding the magnitude of collateral blood flow and the severity of the coarctation.

ATRIAL SEPTAL DEFECT

Atrial septal defects (ASDs) account for 4% to 10% of congenital cardiovascular defects and about one third of cases of adult congenital heart disease. The size of the ASD (which has a major influence on the magnitude of intracardiac shunting), the relation of the defect to adjacent intracardiac structures, and the presence of associated congenital anomalies—important factors in determining the appropriate intervention—can be readily determined with CMR. Twenty percent of ASDs close spontaneously in the first year of life; only 1% of patients become symptomatic in the first year, with an associated mortality rate of 0.1%. Unrepaired ASDs, however, are associated with a 25% lifetime risk of mortality, mainly owing to the development of right heart failure, pulmonary vascular obstructive disease, cardiac arrhythmias, or paradoxic emboli. Thus, ASDs are typically repaired surgically or by transcatheter closure if they have not closed spontaneously by early childhood.

Use of transthoracic or transesophageal echocardiography (TEE) has been the gold standard for defining atrial septal anatomy, but echocardiography does not provide the detailed information that is obtainable with CMR. In addition, CMR may identify associated anomalies that occasionally are present in patients with secundum ASD. Anomalous pulmonary venous return, mitral valve prolapse, and mitral regurgitation are some associated abnormalities that, when identified, may alter therapeutic decisions. Figure 5 is a 4-chamber CMR...
CARDIAC MAGNETIC RESONANCE IMAGING

In patients with ASDs, the pulmonary-to-systemic blood flow ratio (Qp/Qs) is measured by velocity-encoded CMR to determine the severity of intracardiac shunting. Oximetry during cardiac catheterization is the classically accepted method, but CMR can accurately determine this information noninvasively. In 20 adults and children aged 9 years or older who had a secundum ASD or patent foramen ovale, Qp/Qs was measured by phase-velocity cine CMR and by oximetry during catheterization for transcatheter closure of the defect. The researchers observed close agreement between the 2 techniques. In fact, CMR measurements of Qp/Qs tended to correlate better with the size of the ASD.

Durongpisitkul et al found that a large posterior-inferior rim is the most important predictor of successful transcatheter closure of an ASD. The investigators conducted a prospective study, in which 66 adults and children older than 8 years of age with an isolated secundum ASD underwent both TEE and CMR prior to closure of the defect. In 10 patients, TEE did not adequately measure the posterior-inferior rim, whereas CMR visualized the rim adequately in all patients. Children can undergo CMR successfully; some require sedation, whereas others are content with having a parent near the head of the machine. Beerbaum et al prospectively studied 65 consecutive children with a secundum ASD (mean age, 5 years; range, 1-15.7 years) who had inconclusive results on transthoracic echocardiography. Phase-contrast CMR and magnetic resonance angiography were used to determine whether transcatheter defect closure was feasible. Subsequently, TEE was performed during transcatheter closure or, if the child was deemed unfit for transcatheter closure, during catheterization prior to surgery. Thirty of the 65 patients were referred for the transcatheter procedure based on CMR findings, and 25 of these procedures were successful. In the other 5 children, CMR missed ASDs that were too large for transcatheter intervention because the image did not reliably depict septal thickness. In 17 patients, however, CMR identified multiple defects and/or associated vascular anomalies. In the diagnosis of ASD and vascular anomalies, there were no false-positive or false-negative results when CMR findings were compared with the results of catheterization, TEE, or surgery.

At Duke University, an analysis of 34 consecutive patients compared CMR with oximetry during cardiac catheterization for the evaluation of shunt magnitude. Shunt magnitude measurement by CMR was accomplished using 2 methods. In one CMR method, pulmonary artery and aortic blood flow were measured using velocity-encoded imaging. In the second method, the plane of the atrial septum was defined, and through-plane velocity-encoded imaging subsequently was used to measure blood flow through the ASD directly. Both of the CMR techniques correlated well with catheterization-measured shunt magnitude (Table).

Cine sequence 4 is a true-FISP image sequence of a patient with a secundum ASD. In this sagittal view of the atria, the defect is just posterior to the ascending aorta. Cine sequence 5 is a velocity-encoded image in the same plane, demonstrating blood flow (coded in black) from the left atrium into the right atrium. Once an image of the blood flow is obtained, an imaging plane exactly perpendicular to the flow can be chosen to provide en face imaging of the blood flow through the defect.

Cine sequence 6 is an example of en face velocity-encoded imaging of a patient with a secundum ASD, taken in the plane of the atrial septum. Blood flow moving out of the imaging plane, toward the viewer, is

| Table. Evaluation of Atrial Septal Defect Shunt Magnitude by Cardiac Magnetic Resonance Imaging vs Cardiac Catheterization Oximetry* |
|-----------------|--------|--------|--------|--------|
| Measurement     | CMR    | Cath   | r      | P value |
| Qp/Qs (vel-enc PA/Ao) | 1.0–3.1 | 1.0–2.5 | 0.70   | < .0001 |
| Direct ASD flow (L/min) | 0.6–10.8 | 0.4–6.1 | 0.72   | < .0001 |

* N = 34.

CMR = cardiac magnetic resonance imaging; Cath = cardiac catheterization oximetry; Qp = pulmonary blood flow; Qs = systemic blood flow ratio; vel-enc PA/Ao = velocity-encoded pulmonary artery to aortic blood flow ratio; ASD = atrial septal defect.

Data from Crowley et al.
encoded black and in this case represents flow from the left atrium to the right atrium through the secundum ASD. This technique reveals the morphology of the ASD as a black teardrop-shaped defect in the cephalad and anterior portion of the atrial septum. These images provide data about the size and shape of the defect, as well as detailed anatomy of the atrial septum and how the defect relates to nearby intracardiac structures. The image data are helpful in formulating a treatment strategy prior to ASD closure.

Crowley et al have found that en face velocity-encoded CMR provides important information that can influence clinical management. CMR imaging detected multiple defects, inadequate posterior inferior tissue, or associated cardiovascular anomalies in 9 of 39 patients with ASDs. These problems were not detected by transthoracic echocardiography or TEE.16

In providing information about associated anomalies, CMR may prevent patients from undergoing inappropriate procedures and may decrease the risk of complications, such as device erosion or embolization, by providing greater preprocedural anatomic detail. Figure 6A shows a patient with a small (8-mm diameter) secundum ASD and more right ventricular enlargement than would be expected for a defect of this size. Figure 6B demonstrates that the pulmonary venous return from the right upper pulmonary vein is connected to, and flow is committed anteriorly into, the superior vena cava at the right atrial junction. These CMR images demonstrate that this individual not only has a secundum ASD, but also partial anomalous pulmonary venous return from the right upper lung to the superior vena cava. This congenital anomaly requires surgical correction rather than a percutaneous approach. The example shows how important information can be obtained noninvasively by using CMR imaging, thereby preventing an inappropriate procedure.

A study that is under way at Duke University is investigating the long-term outcomes of patients who undergo percutaneous closure for secundum ASDs. CMR provides quantitative data regarding ventricular function and volume after ASD closure. Early findings demonstrate a 30% mean reduction in right ventricular volume 6 months after ASD closure.

**CARDIOMYOPATHIES**

Cardiomyopathies are responsible for approximately 20% of all cases of sudden death in adults younger than 40 years.17 Sadly, sudden cardiac death often is the first manifestation of underlying cardiomyopathy—there are no warning signs, which makes it difficult to establish clear etiologies. Often, clues to the epidemiology come from postmortem pathologic studies, which have highly variable results, with the incidence of myocarditis ranging from 0 to 80%.17 In 5% to 10% of cases, myocarditis progresses to dilated cardiomyopathy18 for which the 5-year survival rate is 50%.2

**MYOCARDITIS**

Mahrholdt et al performed inversion recovery gradient-echo pulse sequences on 32 patients who had received a diagnosis of myocarditis by clinical criteria.18 Myocarditic lesions, indicated by contrast enhancement, were detected in 28 patients. In 21 of those patients, the researchers obtained endomyocardial biopsy specimens from the region of contrast enhancement; 19 of these specimens revealed active myocarditis. In addition to being valuable for diagnosis, CMR was helpful in monitoring myocarditis. Areas of myocardial scarring decreased over time as ejection fraction and end-diastolic volume returned to normal.

**RESTRICTIVE CARDIOMYOPATHY**

CMR also can be used diagnostically in patients with restrictive cardiomyopathy. Cine sequence 7 is a 4-chamber image that demonstrates a nondilated left ventricle with mild global reduction in systolic function. Mitral and tricuspid regurgitation and bialtrial enlargement are also noted. Figure 7 is a short-axis CMR image of the same patient, obtained using DHE, showing light grey abnormal myocardium contrasting with islands of dark black normal myocardium. Note the patchy, nonhomogeneous uptake of gadolinium in the left ventricle. Endomyocardial biopsy of this patient revealed amyloidosis.

**HYPERTROPHIC OBSTRUCTIVE CARDIOMYOPATHY**

Evaluation of hypertrophic obstructive cardiomy-
HOCM is another diagnostic application of CMR. Cine sequence 8 depicts marked hypertrophy of the left ventricle, particularly asymmetric hypertrophy of the interventricular septum. It shows the mitral valve, which is displaced anteriorly during mid-systole, narrowing and obstructing the left ventricular outflow tract. Cine sequence 8 also shows the mitral regurgitation that occurs in patients with systolic anterior motion of the mitral valve, a hallmark finding in HOCM.

Patients with HOCM typically have scarring at the septal insertion sites of the right and left ventricles. With gadolinium-enhanced CMR, this scarring can be detected before obstruction develops and before the other morphologic hallmarks of the disease are present.

Ventricular arrhythmias in patients with HOCM might be related to scarring that starts at the left ventricular endocardium and extends through the very thick ventricular septum. Using CMR to detect this scarring, which might help predict ventricular arrhythmias and sudden death in these patients, is an area of active research.

**CORONARY ARTERY DISEASE**

Coronary artery disease (CAD) is the single leading cause of death in the United States. In 2001 there were 1.2 million new and recurrent cases of myocardial infarction (MI) and fatal CAD, and the prevalence of ischemic heart disease was 13.2 million. After MI, the extent of viable myocardium predicts which patients will have increased left ventricular ejection fraction and improved survival after revascularization. Serum enzymes and evaluation of wall motion are used to identify infarcted myocardium, but these methods have limitations that can reduce diagnostic accuracy.

**MYOCARDIAL INFARCTION**

In a prospective study, Choi et al found that DHE images obtained soon after acute MI can distinguish between reversible and irreversible myocardial dysfunction. Contrast-enhanced CMR identified the extent of MI, with the most extensive areas defined as transmural. Regions with very little or no hyperenhancement were classified as viable. Cardiac regions with preserved viability defined by DHE had substantial improvement in the contractile wall motion of the heart after reperfusion. The 24 patients included in this study had presented with their first MI and were successfully revascularized. They underwent CMR within 7 days of MI and again 8 to 12 weeks later. Improvement in left ventricular regional contractile function was inversely related to the transmural extent of infarction defined by DHE ($P = .001$).

Kim et al obtained similar results in patients with chronic ischemic heart disease. They performed DHE imaging in 50 patients, including 21 with a history of MI, before the patients underwent coronary artery bypass graft surgery or angioplasty. In 41 patients, CMR was repeated an average of 79 days after revascularization. Before revascularization, 804 of 2093 myocardial segments analyzed had abnormal contractility on cine CMR. In an analysis of these 804 segments, the likelihood of improvement in contractility after revascularization was inversely related to the transmural extent of infarction on CMR before revascularization ($P < .001$).

Figure 8 shows DHE images of 3 different areas of MI. The left-hand panel shows an anterior infarct caused by a left anterior descending coronary occlusion. Of interest is the endocardial and near-transmural hyperenhancement, the bright areas extending into the anterior wall and along the septum in the short-axis view and extending to the left ventricular apex in the long-axis view. The center panel shows a posterior infarct due to a circumflex coronary occlusion. Note the endocardial hyperenhancement in the posterolateral wall of the left ventricle that extends to the mid-wall. The right-hand panel shows a subendocardial inferior wall MI that involves the base of the heart but does not extend to the apex of the inferior wall.

Cine sequence 9 shows a posterolateral MI that resulted in severe hypokinesia of the posterior lateral segment. Corresponding DHE images show near-transmural infarction in this segment. The small dark “island” area in the center of the bright hyperenhanced region represents a region of no reflow. During the acute MI, necrosis and plugging occurred in some central capillaries, and no perfusion of gadolinium reached these islands of tissue. The lower panels, taken 4 months later, show that systolic function was not recovered in this region of near-transmural DHE. Cine sequence 10 shows only subendocardial DHE in a...
patient with an acute anterior MI. In the image taken at 4 months, note the recovery of systolic function in the anterior, septal, and apical regions of the left ventricle compared with the acute study (upper panels).

**MYOCARDIAL ISCHEMIA**

CMR also can be used to identify patients who have myocardial ischemia rather than infarction. Cine sequence 11 shows normal left ventricular wall motion. The corresponding DHE image (right panel) does not show any bright areas indicative of infarction in this individual. Cine sequence 12 shows a gadolinium bolus injection in this patient, during adenosine infusion, with first-pass imaging as the gadolinium bolus reaches the heart. Adenosine is a vasodilating agent used to increase the coronary flow by dilating the coronary microcirculation. An infusion of adenosine is given over several minutes, and imaging is performed during a second gadolinium intravenous bolus. In cine sequence 12, the bright gadolinium contrast can be seen entering the right ventricular chamber and, a few cardiac cycles later, the left ventricular chamber. Finally, the left ventricular myocardium becomes bright as the gadolinium perfuses into the coronary circulation and thereby into the myocardial space. As the gadolinium reaches the myocardium in this case, the lateral and inferior walls perfuse promptly (become light grey). However, the anterior and septal regions remain dark, filling with gadolinium later compared with the surrounding myocardium, demonstrating that endocardial perfusion is delayed in the anterior and septal regions of the left ventricle. At cardiac catheterization, this patient was found to have severe single-vessel disease in the left anterior descending coronary artery proximal to the first septal perforator.

**NEW TECHNIQUES AND FUTURE APPLICATIONS**

Real-time CMR techniques recently have been developed that do not require respiratory or electrocardiographic gating, so repeated measurements can be made within a few seconds. Thus, it is now possible to use CMR to obtain safe and accurate measurements of blood flow, even in patients with cardiac arrhythmias. In research settings, real-time CMR is being used to determine the effects of respiration and exercise on blood flow, and it eventually may provide hemodynamic information not available from other imaging techniques.22

CMR is being used increasingly in children to evaluate congenital heart abnormalities, particularly abnormalities occurring in extracardiac structures, such as vascular rings. It is a safe and noninvasive method for obtaining information that previously required invasive techniques, and is frequently used for children younger than 8 years of age.23

A potential clinical application for CMR is guidance of catheters and catheter-mounted interventional devices; this application is already being investigated.1 Compared with radiographic approaches, advantages of CMR guidance include freedom from ionizing radiation, direct flow measurement, characterization of varied tissues, and more comprehensive 3-dimensional imaging.

**CONCLUSION**

As it becomes more widespread, more rapid, and more automated, CMR can be expected to make increasingly important contributions to the management of patients with a variety of cardiovascular diseases.

**REFERENCES**


