

Cardiovascular Magnetic Resonance

An analysis of this imaging modality for structural heart disease interventions.

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Cardiovascular magnetic resonance (CMR) is a robust imaging modality with a growing range of clinical applications.

The higher spatial resolution and wider field of view compared to transthoracic echocardiography (TTE) and lack of ionizing radiation and nephrogenic contrast administration compared to multidetector CT (MDCT) position CMR as an attractive noninvasive imaging tool. CMR has been well validated across a range of clinical applications, including the evaluation of myocardial viability, cardiomyopathies, pericardial disease, and valvular heart disease. In light of the rapidly expanding field of percutaneous and transcatheter-based intervention for structural heart disease, this article focuses on the evolving role that CMR imaging plays in structural interventions, particularly in valvular disease and congenital heart disease (CHD).

CMR IN VALVULAR HEART DISEASE

Aortic Valve Disease

Age-related degenerative calcific aortic stenosis is the most common valvular disease in nondeveloping countries and is an important public health problem.¹ Once symptoms develop, the chance of survival is grim, with a mortality rate of 25% per year.² Although surgical aortic valve replacement has traditionally been the mainstay treatment for these patients, many are considered high risk for surgery due to their multiple comorbidities, and they are increasingly being referred for minimally invasive transcatheter aortic valve replacement (TAVR).

Although the diagnosis of aortic valve disease is typically made via echocardiography, CMR is a robust tool that

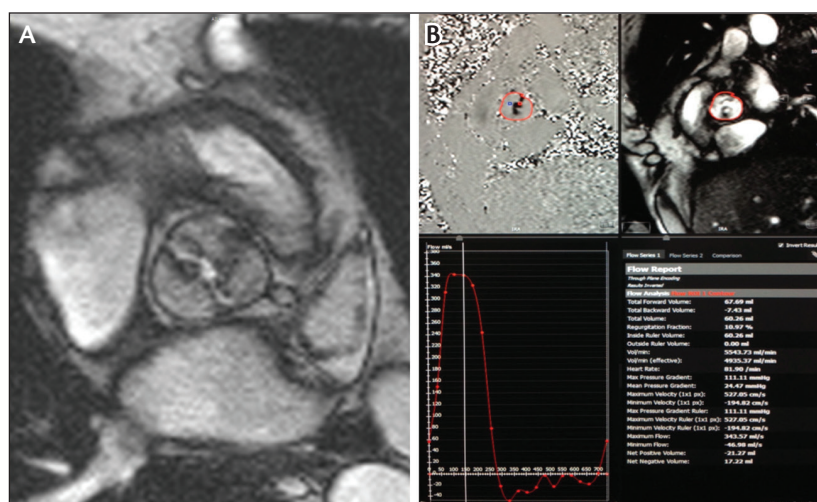


Figure 1. The utility of CMR for quantification of severity of valve disease in a 57-year-old man with severe bicuspid aortic valve stenosis. Systolic phase image of the aortic valve shows fusion of the left and right cusps and severe aortic stenosis with an aortic valve area of 0.8 cm² as determined by planimetry (A). Phase contrast (velocity-encoded) images can be utilized to directly quantify peak aortic valve velocity, as well as aortic regurgitant fraction (B).

can be used to evaluate aortic valve disorders, including stenosis or aortic regurgitation, and should be considered in cases when the severity of disease is unclear on echocardiography.³ Both steady-state free precession and velocity-mapping phase contrast CMR sequences can be used to accurately visualize the aortic valve and provide accurate quantification of the severity of valvular disease (Figure 1).

MDCT has high spatial resolution and allows for multiplanar imaging of the entire aorta and peripheral vasculature, allowing it to emerge as the preferred pre-TAVR imaging modality for determination of annular sizing, coronary ostial distance from the annulus, and comprehensive assessment of peripheral vessels to guide the route of access. However, nearly 20% of potential TAVR candidates were unable to undergo MDCT due to renal impairment or arrhythmia.⁴ In these cases, CMR is

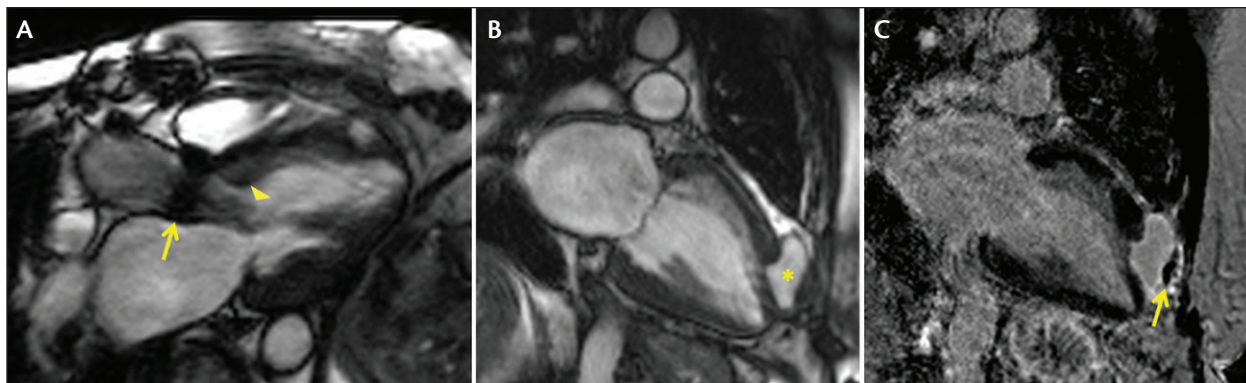


Figure 2. Imaging of an 87-year-old woman after TAVR (23-mm Sapien XT valve, Edwards Lifesciences) complicated by left ventricular apical pseudoaneurysm at the apical access site. CMR revealed a well-seated prosthesis (arrow) but with moderate paravalvular aortic regurgitation (arrowhead) (A), a two-chamber view demonstrating the presence of an apical pseudoaneurysm (asterisk) with narrow neck (B), and late gadolinium enhancement imaging in the two-chamber view demonstrating thrombus (arrow) in the pseudoaneurysm (C). The patient underwent successful transcatheter closure of the pseudoaneurysm with an AVP II vascular plug (St. Jude Medical, Inc.).

an attractive alternative to MDCT that does not require contrast administration and is less dependent on heart rate. In a study of 50 patients referred for TAVR who underwent multimodality pre-TAVR imaging with both CMR and MDCT, no differences were seen between CMR and MDCT in calculation of aortic annulus area.⁵ In addition, there was excellent correlation between CMR and MDCT in determining aortic annulus root geometry and coronary ostial height. One notable shortcoming of CMR is its relative inability to evaluate the calcification burden. Other studies comparing CMR and MDCT prior to TAVR have found similar results,^{6,7} including patients undergoing valve-in-valve procedures.⁸

Postprocedure imaging is immediately performed after valve deployment, as well as during long-term follow-up. Typically, intraprocedure transesophageal echocardiography is utilized to confirm valve placement and to evaluate paravalvular leak (PVL), post-TAVR hemodynamics, valve area, and gradients. Immediate recognition of suboptimal valve positioning may allow for adjustment of the valve (depending on the type of valve used). In the longer term, CMR imaging after valve implantation allows for surveillance of aortic regurgitation, PVL, residual aortic stenosis, associated mitral valve regurgitation, valve migration, and apical access site complications, such as aneurysm and pseudoaneurysm (Figure 2).

Moderate or severe PVL after TAVR occurs in > 10% of patients and portends a worse overall prognosis.⁹ Acoustic shadowing and eccentric regurgitation jets from the valve limit the diagnostic accuracy of TTE, whereas the invasive nature of transesophageal echocardiography is less desirable from the patients' perspective. CMR is a robust tool for predicting and quantitatively evaluating

PVL. In addition, CMR is useful for anatomic assessment of PVL, should further percutaneous interventions with closure devices be needed. Several studies have demonstrated that pre-TAVR CMR can forecast postprocedural PVL, with larger aortic annulus measurements being most predictive of significant postprocedure regurgitation.^{6,10} In addition, when CMR was compared to TTE in 23 symptomatic patients at 1 year after TAVR, the severity of PVL was reclassified in approximately half of the patients. Moreover, patients with greater than mild PVL by CMR experienced reduced event-free survival for the primary endpoint of all-cause death, heart failure hospitalization, or further invasive therapy.¹¹

Myocardial injury after TAVR has been described as a risk factor associated with increased mortality.¹² Compared to patients without late gadolinium enhancement seen on CMR imaging after TAVR, those with late gadolinium enhancement were noted to have a decreased left ventricular ejection fraction at discharge.¹³ Late gadolinium enhancement before TAVR was also shown to be associated with higher cardiovascular disease–related mortality during long-term follow-up.¹⁴

Therefore, CMR is an imaging modality that is useful in TAVR planning, particularly in patients with renal insufficiency, to accurately characterize the aortic annulus morphology and dimensions. In addition, CMR (both before and after the procedure) aids in further risk stratification of potential complications (especially PVL) and prognostication.

Mitral Regurgitation

Similar to aortic stenosis, the prevalence of mitral regurgitation (MR) increases with age; by the age of 75 years,

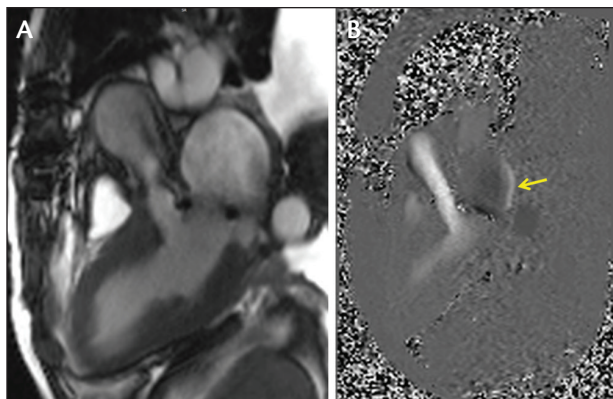


Figure 3. A 58-year-old man after bioprosthetic mitral valve replacement with worsening dyspnea on exertion was found to have endocarditis with severe paravalvular MR. The systolic frame of a three-chamber cine image of a bioprosthetic mitral valve prosthesis (A). Phase contrast (velocity-encoding) in the same three-chamber plane depicting a posteriorly directed paravalvular regurgitant jet (arrow, B).

nearly 10% of patients in a large population study had MR.¹ Compared to patients without MR, those with MR (either primary or secondary) have a worse overall prognosis. Recent guidelines by the American Heart Association and the American College of Cardiology advocate routine surveillance via echocardiography for all patients with MR for progressive disease, ventricular function, and chamber size.¹⁵

The management of MR is controversial. For both primary and functional mild-to-moderate MR, treatment of underlying comorbidities (including heart failure, arrhythmias, and management of volume status) is standard practice. As MR progresses to a severe state, surgical repair or replacement of the mitral valve should be considered. There are also various recommendations for when MR coexists with other disease entities, such as coronary artery disease or left ventricular dysfunction.

With advances in transcatheter technology, percutaneous interventions are now available to treat MR, including mitral valve replacement, leaflet repair, and annuloplasty.¹⁶ Prior to any planned procedures, precise quantification of MR should be performed. Although echocardiography is the first-line imaging tool, CMR has emerged as an important adjunct that has been validated for quantification of MR against both echocardiography and cardiac catheterization.¹⁷⁻¹⁹ The advantages of CMR over echocardiography include precise quantification of regurgitant volumes using several volumetric methods and the ability to accurately assess MR in the setting of eccentric or multiple regurgitant jets. Moreover, CMR allows for detailed information

regarding the impact of MR on left ventricular size and function (Figure 3).²⁰

Percutaneous mitral valve repair using the MitraClip device (Abbott Vascular) is a growing platform to treat patients with severe, symptomatic MR using a minimally invasive approach compared to traditional surgical options. In standard and high-risk patients, improvements in the degree of MR and positive ventricular remodeling after MitraClip implantation have been demonstrated by echocardiography in the EVEREST II cohort and several other studies.²¹⁻²³ Furthermore, improvements in New York Heart Association functional class and clinical symptoms have been described.²⁴ In cases when echocardiography is limited due to acoustic shadowing or poor windows, imaging after MitraClip implantation can be accomplished with CMR, which is a safe, reliable, and effective tool to assess response in this patient population. Several CMR-based studies have reported improved left ventricular dimensions and volume, left ventricular ejection fraction, mitral annulus diameter, and myocardial mass.^{25,26}

CONGENITAL HEART DISEASE

The incidence of all types of CHD is 75 per 1,000 live births, whereas the incidence of moderate to severe forms of CHD is approximately six per 1,000 live births.²⁷ Early detection of CHD and rapid advances in treatment options have permitted many children with CHD to live into adulthood. Consequently, adults with CHD now face a variety of sequelae that are potentially amenable to percutaneous intervention.

In addition to echocardiography and CT imaging, CMR has long been used in the evaluation of both pediatric and adult CHD.²⁸ Atrial or ventricular septal defects and patent foramen ovale are best detected by echocardiography, but CMR is also well suited to distinguish more unusual locations of septal defects (eg, sinus venosus defects) and allows for accurate calculation of shunt quantification and chamber size and function.²⁹⁻³¹ In addition, by using a variety of magnetic resonance imaging sequences (including black blood, steady-state free precession, and phase contrast), CMR can be used to measure the size of septal defects for planned percutaneous closure with occluder devices.

Children with symptomatic coarctation of the aorta typically undergo surgical resection at a young age. Residual stenosis is common, and in some instances, poststenotic aneurysm formation occurs. Monitoring with echocardiography is challenging because the imaging windows often become poor as the child grows. Repeated examination with CT leads to cumulative radiation exposure, and multiple cardiac catheterizations are invasive and

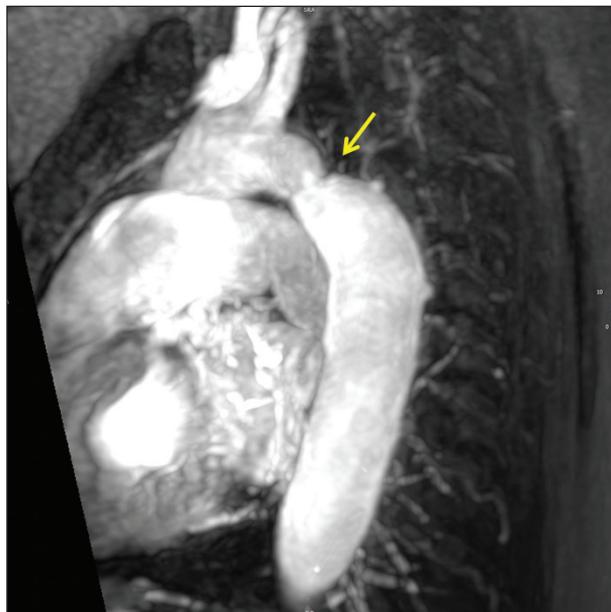


Figure 4. A 39-year-old woman with dyspnea on exertion was found to have an ascending aorta to descending aorta peak-to-peak gradient of 43 mm Hg. A maximum-intensity projection image from contrast-enhanced, three-dimensional, gated aortic magnetic resonance imaging shows coarctation of the aorta (arrow) measuring 16 X 11 mm distal to the left subclavian artery. The patient underwent successful stent placement of the coarctation with a residual peak-to-peak gradient of 15 mm Hg.

also expose the patient to radiation. As such, CMR is often utilized instead (Figure 4). Hemodynamic data from CMR have been shown to correlate well with pressure gradients across the coarctation as measured by invasive catheterization.^{32,33} CMR findings also provide predictive information regarding when further intervention (either percutaneous or surgical) for coarctation of the aorta is necessary. A model incorporating parameters derived from CMR (indexed minimum aortic area and deceleration time in the descending aorta) had an area under the curve of 0.99 for predicting intervention.³³

In patients with tetralogy of Fallot, the most common cyanotic CHD, surgical treatment to correct right ventricular outflow tract obstruction and repair the septal defect takes place in childhood. However, in the long-term, complications from consequent pulmonic regurgitation can result in progressive right heart failure, which is associated with both morbidity and mortality. Additionally, the right ventricle to pulmonary artery conduit that is created surgically is prone to stenosis. CMR allows for serial monitoring of right ventricular function, and CMR contrast angiography can detail the area of the conduit.²⁸ Therapeutic interventions include stenting of the conduit

for hemodynamically significant stenosis. Although percutaneous pulmonary valve replacement is far less common than TAVR or percutaneous mitral valve repair at present, it is likely that this will become a growing area of investigation in the future.

ON THE HORIZON

For years, electrophysiologists have utilized electromagnetic maps overlaid with CT or CMR images, improving their ability to identify regions/areas of interest for catheter-directed therapies, such as radiofrequency ablation, in patients with arrhythmias. CMR is better suited to identify areas of interest than CT, as it can help account for innate cardiorespiratory motion.³⁴ Interventional cardiology has only started to appreciate the potential for real-time CMR in the cardiac catheterization laboratory. The development of gadolinium-filled, balloon-tipped catheters has recently allowed for real-time, CMR-guided right heart catheterization.³⁵ Additionally, animal studies with real-time CMR have shown early success in a variety of procedures, including closure of septal defects; stenting of the iliac, renal, and carotid arteries; and even TAVR.³⁴ It is conceivable that in the future, CMR will have a role in real-time interventional management of patients.

CONCLUSION

The tremendous growth in percutaneous structural heart interventions has helped foster a growing need for noninvasive, accurate assessment of detailed cardiac anatomy and function. CMR is an accurate and versatile imaging tool that complements existing imaging techniques and has been validated across a range of clinical scenarios in valvular heart disease and CHD for both preoperative assessment and postoperative surveillance. ■

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