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FUNCTIONAL VALVE ASSESSMENT: THE EMERGING ROLE OF CARDIOVASCULAR MAGNETIC RESONANCE

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Introduction

The prevalence of valvular heart disease is increasing along with the life span of the population. In assessing individuals with valve disease, echocardiography is the primary imaging modality used by clinicians both for initial assessment and for longitudinal evaluation. Information regarding valve morphology and function, cardiac chamber size, wall thickness, ventricular function, and estimates of pulmonary artery pressures can be readily obtained and integrated to formulate an assessment of valve disease severity. In some instances, body habitus or the presence of coexisting lung disease may result in suboptimal acoustic windows on echocardiography, which may lead to technically difficult studies. Additionally, in some patients, information from clinical history and physical examination or other diagnostic tests may be discordant with echocardiographic findings. In these instances, there is a significant clinical role for cardiovascular magnetic resonance (CMR).

The diagnostic capabilities of CMR have increased substantially over the past 20 years due to hardware and software advances. Today, CMR has a number of unique advantages over other imaging modalities — primarily, it provides a view of the entire heart without limitations from inadequate imaging windows or body habitus. Furthermore, CMR can obtain imaging data in any imaging plane prescribed by the scan operator, which makes it ideal for accurate investigation of all cardiac valves — aortic, mitral, pulmonic, and tricuspid. In addition, CMR for valve assessment is noninvasive, free of ionizing radiation, and in most instances does not require contrast administration.

Since a comprehensive review of the role of CMR in all valve lesions is beyond the scope of this article, we will focus on the most common valvular indication for performance of clinical CMR studies in our laboratory: mitral insufficiency. The following provides a description of the CMR techniques and an overview of selected validation and reproducibility studies.

The objectives of a comprehensive CMR study for evaluating mitral insufficiency are threefold: 1) to provide insight into the mechanism of mitral insufficiency, 2) to quantify the severity of mitral insufficiency, and 3) to discern the consequences of the lesions including the effects on left ventricular (LV) volume, LV systolic function, and left atrial volumes. In most instances this information can be obtained without the need for intravenous contrast agents (gadolinium). Therefore, CMR can be performed even in patients with severe renal failure.

CMR Technique

The typical CMR study for evaluating mitral insufficiency involves the performance of a complete set of sequential short-axis (every 10 mm from base to apex) and long-axis (typically standard 2-, 3-, and 4-chamber views) cine images using a steady-state free precession (SSFP) pulse sequence. This provides excellent signal-to-noise ratio and high blood-to-myocardium contrast. The typical spatial resolution is 1.5-2.0 mm per pixel with 6 mm slice thickness. Using this ultrafast pulse sequence, temporal resolution of 25-35 msec (frame rates of 30-40/second) can be achieved within a 5-6 second breath hold that is generally tolerable for most patients even in the presence of severe valvular disease. In individuals who have significant difficulty with breath holding, a newer non-breathheld "real-time" pulse sequence with parallel imaging can be used with only a modest compromise in spatial and temporal resolution.

An example of a typical series of cine images is shown in Figure 1. In addition to providing a comprehensive assessment of regional LV and right ventricular (RV) function, this data set can be used to planimeter LV and RV volumes in end-diastole and end-systole, thus determine ventricular stroke volume and ejection fraction. Additionally, planimetry of epicardial contours can be performed to obtain ventricular mass. Because of the tomographic nature of the technique, CMR is able to provide these measures in a 3D fashion without the need for geometric assumptions, and it in-fact is considered the gold standard, with extensive validation in both the in vivo and ex vivo settings.[1]

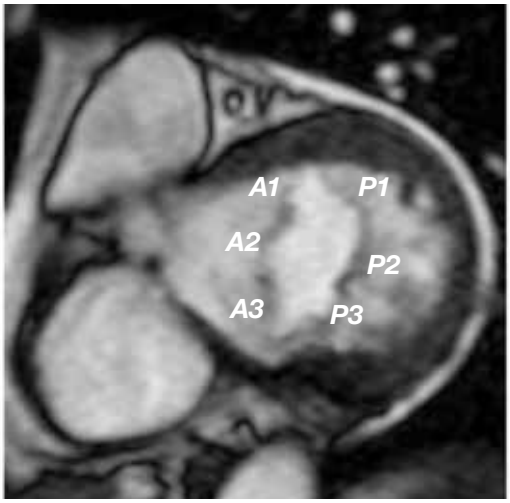

Figure 2. Anatomy of the mitral valve shown in a cross section during mid-diastole. The three segments or scallops of the anterior mitral leaflet are labeled A1, A2, and A3. The three segments or scallops of the posterior mitral leaflet are labeled P1, P2, and P3.

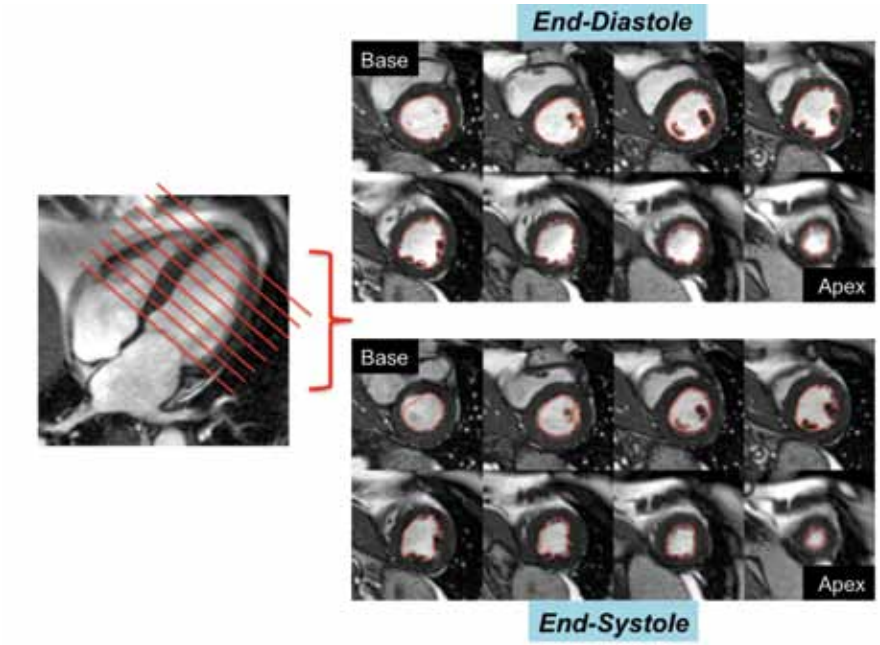

Figure 1. Typical set of cine images utilizing a steady-state free precession pulse sequence. From a 4-chamber long axis view, serial short-axis cine images are acquired every 1 cm from base to apex of heart. The left ventricular (LV) endocardial contours are planimetered in both end diastole and end systole and summed to calculate LV end diastolic volume (LVEDV) and LV end systolic volume (LVESV). The difference between LVEDV and LVESV represents the LV stroke volume. LV ejection fraction (%) can be calculated by dividing the LV stroke volume by the LVEDV and multiplying by 100. The same can be performed for the right ventricle (RV) to ascertain RV end diastolic volume, RV end systolic volume, RV stroke volume, and RV ejection fraction.

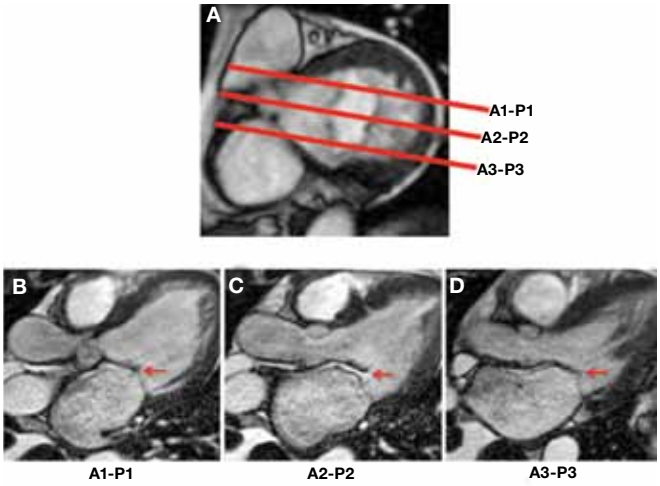

Figure 3. CMR interrogation of the mitral valve. Using a cross-sectional view of the mitral valve as a reference point (A), serial long-axis views are prescribed through the A1-P1 scallops (B), the A2-P2 scallops (C), or the A3-P3 scallops (D) to produce long-axis cine views interrogating the individual scallops and coaptation points of the mitral valve. In this example, there is adequate coaptation of the A1-P1 scallops (B) and the A3-P3 scallops (D) but impaired coaptation of the A2-P2 scallops, demonstrating a flail P2 scallop (C).

Mechanism of Mitral Insufficiency

Before we discuss the CMR method for quantification of mitral regurgitation severity, it is important to recognize that CMR may be able to provide useful information regarding the mechanism of mitral insufficiency. An understanding of the mitral valve anatomy is required to perform optimal imaging with CMR. The mitral valve consists of two leaflets, anterior and posterior, with each leaflet subdivided from top to bottom into three segments or scallops: A1 (lateral), A2 (middle), and A3 (medial) for the anterior leaflet, and P1, P2, and P3 for the posterior leaflet (Figure 2).[2, 3] When imaging a patient with suspected mitral valve abnormality, it is essential that all scallops of the mitral valve leaflets are interrogated with individual cine images. This is accomplished by performing the sequential long-axis cine slices through each scallop as is shown in Figure 3. This provides long-axis views that interrogate all of the valve coaptation interfaces (A1-P1, A2-P2, and A3-P3), provides insight into mechanism (i.e., prolapse, flail, restricted), and also aids in localization of the abnormality. This information can be crucial for the surgeon in gauging the likelihood of

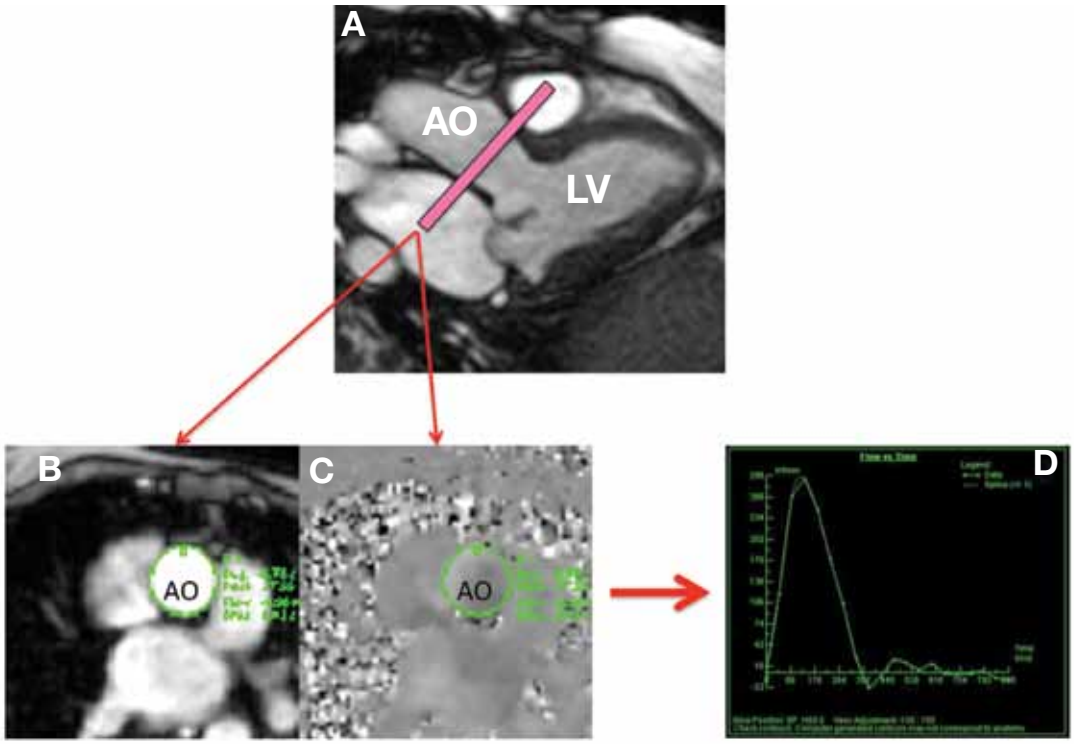

Figure 4. Phase contrast CMR of the aorta to determine aortic stroke volume and flow. Utilizing a three-chamber cine view for reference (A), a phase contrast CMR slice is prescribed in the aortic root (just above the aortic valve). This produces two sets of images: (B) the magnitude image provides details of the anatomy, contour, and shape of the aorta, and (C) the phase velocity map depicts the velocity and direction of flow in each pixel within the aorta. By outlining the contours of the aorta throughout each phase in the cardiac cycle, a flow curve can be generated (D) to determine aortic forward and reverse stroke volume and flow. AO = aorta; LV = left ventricle.

valve repairability. CMR has the potential to visualize all parts of the valve (leaflets, chordae tendineae, and papillary muscles) throughout the entire cardiac cycle. Congenitally abnormal valve leaflets , aberrant papillary muscles or aberrant chordal attachments (parachute mitral valve), leaflet thickening, presence and extent of calcification, leaflet redundancy and prolapse, and commissural fusion are all anatomic descriptions that have been reported by CMR.[4]

Quantification of Severity of Mitral Insufficiency

The phase contrast or velocity-encoded cine CMR pulse sequence is the imaging sequence of choice in quantifying flow and calculating velocities. Protons moving along a magnetic field gradient acquire a phase shift relative to stationary spins.[5] The phase shift is directly proportional to the velocity of the moving protons in a linear gradient. Phase contrast CMR produces two sets of images: magnitude images and phase velocity maps (Figure 4). The magnitude image is used for anatomic orientation of the imaging slice and to identify the boundaries of the vessel imaged. The phase map encodes the velocities within each pixel. Using both images, a region of interest can be traced at each time frame of the data set. The region of interest must be drawn carefully for each frame of the cardiac cycle because of movement and deformation of the vessel.[4] Using this data, the computer software can calculate antegrade and retrograde flows through a region of interest (Figure 4).

Phase contrast CMR has been shown to be very accurate for assessing antegrade and retrograde flow across semilunar valves and therefore is the technique used for assessing aortic or pulmonic insufficiency.[1, 4, 6] This technique for the mitral valve is more difficult because of significant movement of the mitral annulus during systole. For this reason, quantification of mitral insufficiency volume is performed using an alternative approach. In patients with mitral insufficiency, the total LV stroke volume is increased and is equivalent to the aortic forward stroke volume (antegrade flow) plus the mitral regurgitant volume (retrograde flow) (Figure 5). Since the total LV stroke volume can be calculated from planimetry of the LV end-diastolic and end-systolic contours (as shown in Figure 1), and the aortic forward flow can be calculated from phase contrast CMR at the aortic

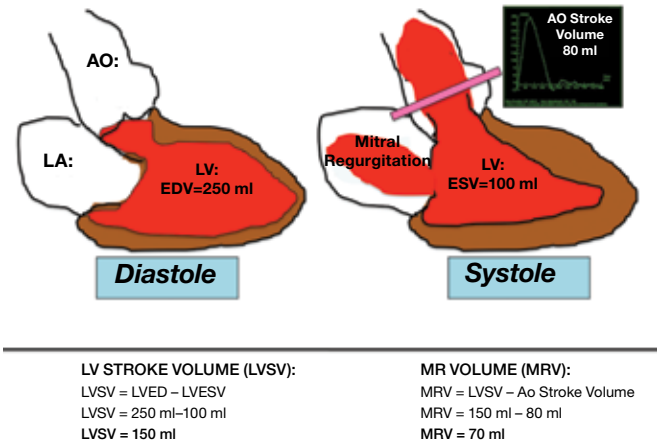

Figure 5. Example of the method used to calculate mitral regurgitant volume (see text for details). AO = aorta; LA = left atrium; LV = left ventricle; EDV = end diastolic volume; ESV = end systolic volume; MR = mitral regurgitation.

Selected Validation Studies: Mitral Insufficiency Quantification

First Author (Year)	CMR Method	Reference Standard: Method	n	r
Fujita (1994)	Velocity mapping: (LV mitral inflow—Ao outflow) RV and RF	TTE: jet area	29	RV 0.74 RF 0.87
Hundley (1995)	Velocity mapping: (LV cine and aortic phase contrast)	catheterization: RV index	23	0.97
	RV index and RF	RF		0.96
Kizilbash (1998)	Velocity mapping: (LV cine and aortic phase contrast) RF	TTE:		
		pulsed Doppler RV	22	0.92
		pulsed Doppler RF	22	0.82

Table 1.

Reproducibility Studies: Mitral Insufficiency Quantification

First Author (Year)	CMR Method	n	CMR Reproducibility*: Mean Difference±1 SD
Fujita (1994)	velocity mapping: (LV mitral inflow-Ao outflow) RV and RF	29	RV r=0.99 RF r=0.98
Hundley (1995)	velocity mapping: (LV cine and aortic phase contrast) RV index and RF	23	FSV 3±3% TSV 9±7% RF 10±9%
Kon (2000)	velocity mapping: (LV cine and aortic phase contrast) RF	28	VM 0.6±4.8%‖ VM—2±7.7%

Table 2.

root (as shown in Figure 4), the difference between these values will be equal to the mitral insufficiency volume. This technique provides accurate calculations in the setting of isolated mitral insufficiency and also in the setting of coexisting aortic insufficiency, since aortic insufficiency increases both the LV stroke volume and aortic forward flow but leaves the difference between the two values unaffected. Selected validation studies are shown in Table 1. Calculation of regurgitant volumes by CMR also has low study variability as is demonstrated in several studies evaluating reproducibility of regurgitant volume assessment (Table 2). This makes CMR an optimal technique for serial assessment of mitral insufficiency in patients who are managed expectantly.

Conclusion

CMR has emerged as a robust new imaging technique for the assessment of patients with valvular disease. Today, CMR has a number of unique advantages over other imaging modalities. CMR is able to provide information regarding the mechanism of valve disease, quantify the severity of disease, and discern the consequences of the lesions including the effects on LV volume, LV systolic function, and left atrial volumes. There also are no issues of image quality from inadequate imaging windows or body habitus. In most instances information can be obtained noninvasively, without the need for intravenous contrast agents or ionizing radiation. Low inter-study variability also makes it an optimal technique for serial assessment of valve disease in patients that are managed expectantly.

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