Valvular and Hemodynamic Assessment with CMR

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- Cardiovascular magnetic resonance
- Valve disease • Hemodynamic assessment
- Flow quantification • Cardiac anatomy

The unique capabilities of CMR are well suited to the assessment of valvular function and hemodynamics of the heart. In particular, the combination of several techniques (anatomic and functional imaging, flow quantification, and angiography) allows a full assessment that would not be possible with only one or two components of the study. The ability to image all areas of the heart and surrounding vessels allows the identification of narrow pathways, conduits, and shunts that can be difficult or impossible to visualize by other means, and their hemodynamic impact on the heart can be assessed. Clear views of outflow tracts can be obtained, even in complex congenital conditions, along with valvular anatomy (including orifice area by direct planimetry rather than calculation) and assessment of anomalous vessel positions that may be important (eg, drainage of the pulmonary veins in cases of suspected sinus venosus atrial septal defects).

The section on hemodynamic assessment includes flow and its relationship to function but excludes left and right ventricular contractility and diastolic function assessment because they are dealt with in the article by Grothues and colleagues, elsewhere in this issue.

ADVANTAGES OF CARDIOVASCULAR MAGNETIC RESONANCE

Accurate and Reproducible Volumes, Function, and Mass

Precise measurements of left ventricular (LV) and right ventricular (RV) volumes, function, and mass are vital for assessing the impact of valvular and hemodynamic lesions on both ventricles, which can ultimately lead to ventricular failure if the impact is great. Cardiovascular magnetic resonance (CMR) is the most accurate and reproducible technique for assessing ventricular volumes and mass,[1–3] and RV volumes are difficult to achieve by other methods. Additional insights into the effect of valve disease on the myocardium may also be gained, for example, by accurately measuring LV mass in patients with aortic stenosis, rather than relying on wall thickness. Reproducibility is important for serial assessment, because valvular and other hemodynamic lesions are often present for many years or even decades before cardiac deterioration or symptoms are present, and long-term follow up is important. By its very nature as a three-dimensional technique, CMR is more sensitive to changes in volume or mass than a unidimensional technique (eg, left ventricular diameter). The latter is also more prone to measurement error because the exact position for measurement has the potential to vary, despite guidelines which aim to standardize the measurement.[4] Precise measurements of LV or RV function are also required for the quantification of certain valve lesions (eg, mitral or tricuspid regurgitation), in conjunction with flow measurement (see later discussion). Accurate stroke volumes also can be used to quantify isolated valve regurgitation without flow data.[5]

Flow Quantification

The ability to measure flow through an image slice[6] is a major advantage of CMR and a crucial

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aspect of hemodynamic assessment. Whether quantifying the degree of valve regurgitation or the pulmonary/systemic shunt ratio or determining relative flow in vessels, the facility to actually measure flow rather than calculate it from complex equations is a feature unique to CMR.

The measurement of flow is based on a phenomenon of MR. Standard MRI uses the hydrogen nuclei in water molecules, which are placed in a higher energy state than at baseline by the delivery of energy in the form of radiowaves. As they return to their baseline (lower) energy state, they emit a radiofrequency signal that is picked up and turned into an image. This signal, in common with all radiofrequency waves, has a phase and amplitude. If the water molecules are moving through a magnetic field gradient (eg, blood flowing along a vessel inside an MR scanner), the phase of the emitted signal changes. The faster the water is moving, the greater the change in phase (phase shift) of the signal, and this relationship is linear. By measuring the phase shift, the velocity of flowing blood in the selected imaging plane can be measured. The velocity of blood can be measured in line with the image plane (in-plane velocity measurement) or in blood flowing through the plane (through-plane velocity measurement). Flow can be derived from through-plane velocity mapping by measuring the velocity in each voxel in a selected area (eg, the ascending aorta) and integrating these over a time period (eg, one cardiac cycle) to obtain flow.[7] The measurement of flow is normally synchronized to the electrocardiogram, and the formulas for calculating flow are usually built into the cardiac software distributed with each scanner.

The accuracy of flow measurement is excellent for in vitro studies and it correlates well with invasive in vivo measurements.[8–11] In vivo studies are hampered, however, by the lack of a true gold standard technique for comparison; invasive measures of flow rely on complex calculations and assumptions that may not hold true in all cases. Temporal resolution is typically 25 to 45 msec, which is lower than for continuous wave Doppler velocity measurements in echocardiography but is good enough for most flow and velocity measurements. The measurement of peak velocity in a stenotic lesion may be slightly underestimated, however, because of the lower temporal resolution. Flow quantification relies on a homogenous magnetic field and laminar flow in a vessel. Complex (nonlaminar) flow patterns, such as turbulent or high-velocity jets distal to a stenosis, can give rise to additional phase shifts that reduce the accuracy of the measurement.[12] These errors are only significant however above velocities of 3.5 to 4 m/s.[11,13] Using sequences with a short echo-time (approximately 2 msec) can reduce these errors[13] and future applications may use these ultra-short echo time sequences. To achieve the most homogenous magnetic field, the image slice should be at the center of the magnet, and some modern scanners automatically position the patient for flow sequences to achieve this. Errors in velocity (and flow) measurement also can occur because of partial volume effects, in which several velocities occur within a single voxel and an averaged phase shift is measured.[12] In practice, through-plane flow mapping typically has an in-plane resolution of approximately 1 mm, and with thin imaging slices (typically 5–7 mm), partial volume errors are only really a problem for narrow flow jets (eg, tight aortic stenosis).

Advanced in-plane flow sequences can measure velocity in three dimensions, with all three directions measured simultaneously.[14,15] This allows complex flow patterns to be assessed, and future work may examine the use of this technique for clinical work.

Noninvasive Technique Without Ionizing Radiation

The need for multiple serial measurements in valve disease and other conditions that require hemodynamic assessment heightens the need for a safe, noninvasive technique. CMR has both of these features in addition to accurate and reproducible measurements and is well placed for the serial assessment of patients. There are also no reported adverse effects of CMR during pregnancy, either for the mother or fetus, although data in this area are scarce. Young women can have important valve disease diagnosed for the first time when pregnant, and increasing numbers of women with congenital heart disease survive to childbearing age. When important hemodynamic information is required during pregnancy (eg, severity of a valve lesion or coarctation, RV function), CMR is able to provide it, although echocardiography remains the first-line investigation.

DIFFICULT AREAS

Arrhythmias

The main problematic area with CMR assessment of valve disease and hemodynamics is irregular cardiac rhythms. Cine image quality can be reduced, affecting the assessment of ventricular function, although the effect on this is usually small. The accuracy of flow measurement also