Non-Ischemic Heart Disease: A Focus on Technique

Phase Contrast MRI

Gautham P. Reddy, MD, MPH

Department of Radiology
University of California, San Francisco
San Francisco, California 94143-0628
MRI is useful for the qualitative and quantitative functional assessment of the cardiovascular system. Velocity-encoded cine (VEC) phase contrast MRI can be used for quantitative assessment of function. Important abilities of VEC MRI for the quantitative assessment of cardiac function include the quantification of valvular regurgitation and stenosis, measurement of intracardiac shunts, and calculation of collateral blood flow and pressure gradients in coarctation of the aorta.

Cardiac catheterization remains the standard of reference for quantifying function in CHD; however, MRI has some important advantages over cardiac catheterization, including its non-invasiveness and absence of ionizing radiation. Echocardiography remains the primary non-invasive imaging modality used to assess patients with CHD, but VEC MRI is a valuable alternative imaging modality for the appraisal of cardiovascular function.

**Technique:** *Velocity-encoded cine phase contrast MRI*

Velocity flow mapping is most usually used in combination with cine MRI and is therefore referred to as velocity-encoded cine (VEC) MRI. In this phase contrast sequence, protons in motion change their respective phase angles in proportion to velocity [1]. The change in phase angle is mapped on the phase images, and flow velocity is calculated using a standard formula. Phase images distinguish between forward and backward flow. Ordinarily the vessel of interest is interrogated in a plane orthogonal to the vector of flow [2]. VEC MRI has been validated *in vitro* using a flow phantom [3, 4] and *in vivo* by correlating with Doppler ultrasound [4] and by comparing to stroke volumes estimated by cine MRI [5, 6].
Once velocity is mapped using the VEC MRI sequence, the flow volume is determined by multiplying the mean velocity with the mean cross sectional area of the vessel. Pressure gradients can be estimated using the modified Bernoulli equation:

$$\Delta P = 4v^2$$

in which $\Delta P$ represents the pressure gradient in mm Hg and $v$ represents the peak flow velocity in m/sec. VEC MRI allows the quantification of flow volume and velocity, and of pressure gradients in central vessels or surgical conduits [5, 7]. VEC MRI flow measurements can be graphed, and the area under the curve can be integrated to derive the flow volume in one cardiac cycle. Flow and pressure measurements can be employed in a number of clinical applications, including the calculation of shunt volumes, valve regurgitation, pressure gradients across stenoses, and differential flow in the left and right pulmonary arteries.

Limitations of the VEC MRI technique include underestimation of velocity and flow if the vessel of interest is not imaged in a plane orthogonal to the direction of flow, or if partial volume averaging of the vessel occurs [8, 9]. If the maximum velocity value is placed at a value lower than the actual velocity, there is the potential for aliasing [8]. Estimation of pressure gradient has other pitfalls that can lead to underestimation of the gradient. For example, the imaging plane may not be at the site of peak velocity [10], or velocities are averaged over the length of the acquisition because the images usually are not acquired in real time [2].

**Clinical Applications**

**Valvular Disease.** An advantage of MRI over echocardiography in the appraisal of valvular disease is the ability of MRI to quantify regurgitant volume. Aortic or
pulmonary regurgitation can be measured directly by VEC MRI. The regurgitant volume is equal to the retrograde flow during diastole, and the regurgitant fraction is calculated by dividing retrograde flow volume by antegrade flow volume [11]. Flow is measured in the main pulmonary artery to assess pulmonary regurgitation and in the proximal ascending aorta to evaluate aortic regurgitation. Because this method directly measures regurgitation, it can be employed even when there is more than one regurgitant valve.

The pressure gradient across a stenotic valve can be estimated with VEC MRI. Peak velocity can be derived by interrogating the vessel orthogonal to the direction of flow [12], and the pressure gradient can be derived with use of the modified Bernoulli equation.

**Quantification of Shunts.** MRI is a valuable technique for quantifying the degree of shunt lesions [5, 13, 14]. There are two primary approaches for the calculation of shunt severity. Both of these techniques rely on the comparison of right and left ventricular SVs. One method involves the use of volumetric cine MRI to calculate stroke volumes, and the other uses VEC MRI to assess the effective stroke volume, may be preferable because it measures stroke volume directly and can be used in patients with ventricular septal defect or with coexisting valve insufficiency. VEC MRI is used to measure flow in the ascending aorta and in main pulmonary artery [5, 14]. In the absence of a shunt, flow is approximately equal in these two arteries. If a patient has a left-to-right shunt related to an atrial or ventricular septal defect or partial anomalous pulmonary venous connection, flow in the pulmonary artery will be greater than that in the aorta by the quantity of the shunt. With a patent ductus arteriosus, aortic flow is greater than pulmonary flow, and shunt volume is calculated by subtracting pulmonary flow from aortic flow. The opposite relationships hold for right-to-left shunts. VEC MRI
measurement of the ratio of pulmonary artery flow to aortic flow, which is referred to as
the pulmonary-to-systemic flow ratio (Qp / Qs), has been shown to correspond to the
ratio derived by oximetric data obtained at cardiac catheterization [14].

**Coarctation of the Aorta.** Spin echo MRI readily delineates the anatomy in
patients with coarctation of the aorta and can demonstrate enlarged collateral vessels [15,
16]. Functional severity of the coarctation can be assessed with VEC MRI [17, 18]. This
acquisition is prescribed from an oblique sagittal image through the plane of the aortic
arch. Each sequence should be obtained in a plane perpendicular to the direction of
aortic blood flow. To quantify collateral blood flow, flow volume is measured at two
locations in the aorta, the first just distal to the site of coarctation, and the second at the
level of the diaphragm [18]. In normal individuals, flow in the proximal descending
aorta is slightly greater than that in the distal thoracic aorta. However, patients with
coarctation may have greater blood flow distally as a consequence of retrograde collateral
flow into the descending aorta via the intercostal arteries and other aortic branches. The
quantity of collateral circulation is determined by subtracting flow volume in the
proximal descending aorta is from flow in the distal aorta. A recent study reported that
the VEC MRI calculation of collateral flow and the visual appraisal of collateral vessels
are more accurate determinants of hemodynamic significance of the coarctation than are
differential upper and lower extremity blood pressure measurements [19]. Moreover, the
type of surgical therapy may depend on the amount of collateral flow.

The pressure gradient across the coarctation is another indicator of its
hemodynamic significance. By performing VEC MRI through the most severely stenotic
segment, peak flow velocity can be derived [17]. The pressure gradient across the
coarctation can be estimated using the modified Bernoulli equation.
Conclusion

VEC MRI can be used to quantify the cardiovascular function. This information can be a valuable addition to morphological imaging for pre-surgical planning as well as post-operative monitoring. Some important clinical applications of VEC MRI include the quantification of shunts and valvular disease and measurement of collateral blood flow and pressure gradients in aortic coarctation.

References


