

Expert Perspective

Cardiovascular Magnetic Resonance for the Assessment of Pulmonary Arterial Hypertension

CONSTANDINOS PAMBOUCAS, PETROS NIHOYANNOPOULOS

Department of Cardiology, Hammersmith Hospital, Imperial College, London, UK

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Pulmonary arterial hypertension (PAH) is defined as a group of diseases characterised by a progressive increase in pulmonary vascular resistance, leading to right ventricular (RV) failure and premature death. The diagnostic approach to PAH, in terms of imaging and haemodynamic assessment, includes mainly echocardiography, ventilation/perfusion lung scintigraphy, spiral computed tomography and right heart catheterization.¹

Cardiovascular magnetic resonance (CMR) is increasingly used in patients with PAH for the evaluation of pathological and functional changes of both heart and pulmonary circulation. Magnetic resonance imaging is an attractive modality for studying the complex geometry of the right ventricle and pulmonary vasculature, since no assumptions need to be made about the shape or location of the structure being studied. CMR has been successfully used as an accurate and reproducible tool to quantify ventricular volumes and mass in both normal and PAH subjects and normal ranges have been established.^{2,3} Recent technological advances enable the robust implementation of steady-state free precession (SSFP) sequences that provide a substantially higher signal-to-noise ratio than can be obtained by conventional gradient-echo

techniques, along with excellent contrast between myocardium and blood (Figure 1).⁴ The SSFP technique is rapidly becoming the preferred cardiac CMR pulse sequence for acquisition of volumetric data sets of the left and right ventricles (Figure 2).

One of the advantages of CMR is that it provides anatomical measurements and indexes that are not influenced by factors and variables affecting echocardiography, such as detectable tricuspid regurgitation, body habitus, coexisting lung disease, heart rate, posture and hydration status. (Some of these limitations also affect the accepted gold standard method of right heart catheterisation). These anatomical indexes are related to haemodynamic parameters clinically relevant to PAH severity, such as the mean pulmonary arterial pressure. The ventricular mass index (ratio of RV mass to left ventricular mass) is such a CMR-derived variable, which provides an accurate and practical means of estimating pulmonary artery pressure non-invasively in pulmonary hypertension and may provide a more accurate estimate than Doppler echocardiography.⁵ Moreover, short-axis curvature of the maximal leftward displacement of the interventricular septum in patients with pulmonary hypertension may be used as a marker of pulmonary arterial pressure,

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Address:

Constandinos
Pamboucas

58 Sifnou St.,
10446 Athens, Greece
e-mail:

pamboucas@yahoo.co.uk

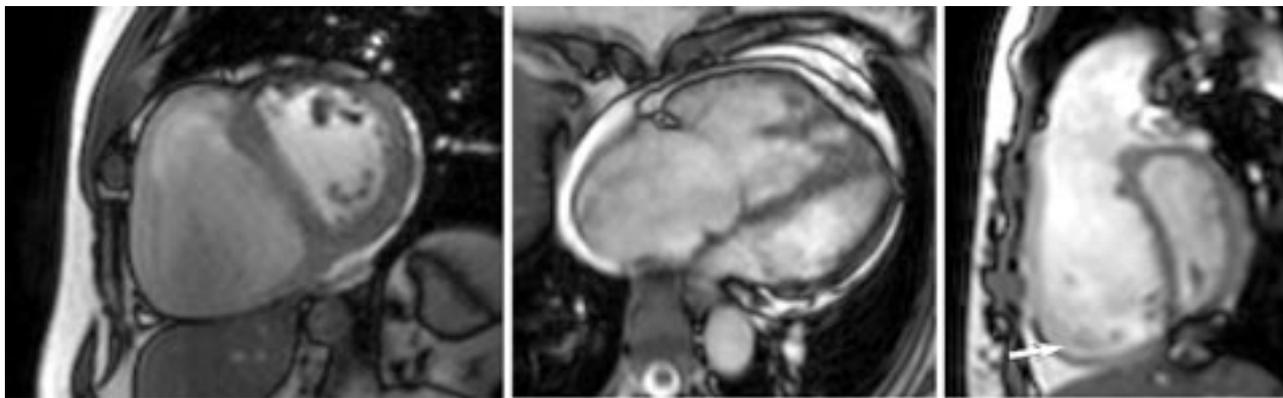


Figure 1. Gradient-echo (bright blood) cine images acquired using the steady-state free precession pulse sequence, from patients with severe pulmonary arterial hypertension. (Left) A short-axis image showing an enlarged right ventricle along with a D-shaped interventricular septal configuration. Interestingly, this septal flattening remains throughout the cardiac cycle, suggesting both systolic and diastolic right ventricular overload. (Middle) A four-chamber view demonstrating right-sided cardiac dilatation. Right atrial enlargement is prominent and increased right ventricular trabeculation can be seen. (Right) A modified right ventricular outflow tract view showing the D-shaped deformity and leftward curvature of the septum. Note the presence of pericardial effusion (arrow), which is a sign of adverse prognosis in patients with pulmonary hypertension.

as there is a significant correlation between these two parameters.⁶

Another CMR approach for the assessment of PAH haemodynamics is phase-contrast velocity mapping. In patients with PAH, velocity-encoded CMR provides measurements of pulmonary flow and right-sided cardiac output similar to those obtained by means of thermodilution, whereas from the quantitative analysis of the pulmonary flow profile, non-invasive indexes (acceleration time, acceleration volume) have been derived for the assessment of pulmonary vascular resistance (Figure 3).⁷ Velocity mapping also enables the non-invasive assessment of mean pulmonary arterial pressure by computing physical parameters (including maximal systolic blood velocity and the cross-sectional area of the main pulmonary artery), and biophysical parameters such as height, weight, and heart rate.⁸

One of the most significant advances in CMR has been the ability to directly visualise the non-viable myocardium by using a segmented inversion-recovery gradient-echo sequence after the intravenous administration of gadolinium contrast. With this technique, termed delayed contrast-enhanced CMR, irreversibly damaged myocardium (fibrosis) is depicted as hyperenhanced (bright).⁹ Recently, it was shown that delayed contrast enhancement was present within the RV insertion points and interventricular septum of most patients with

PAH. Its extent correlated positively with RV end-diastolic volume/body surface area, RV mass, mean pulmonary arterial pressure and pulmonary vascular resistance, and correlated inversely with RV ejection fraction.¹⁰

In terms of evaluation of the pulmonary circulation, gadolinium contrast-enhanced, three-dimensional (3D) magnetic resonance pulmonary angiography is a promising modality for the identification of patients with PAH. A right pulmonary artery diameter value >28 mm is sensitive and highly specific for the diagnosis of chronic PAH.¹¹ Especially in chronic thromboembolic PAH, magnetic resonance angiography seems to have great potential in the detection of vascular changes (central thromboembolic material, vessel cut-offs and abnormal proximal-to-distal tapering), more so than in other causes of PAH.⁴

In order to evaluate pulmonary perfusion, two approaches can be used.¹² The first is contrast-enhanced CMR using 2D or 3D ultrafast imaging sequences. The second approach to perfusion imaging of the lung uses sequences that do not require intravenous contrast agents. These techniques are known as arterial spin labelling, and they use the protons within intravascular blood as an endogenous tracer for the evaluation of blood flow. These methods provide both qualitative and

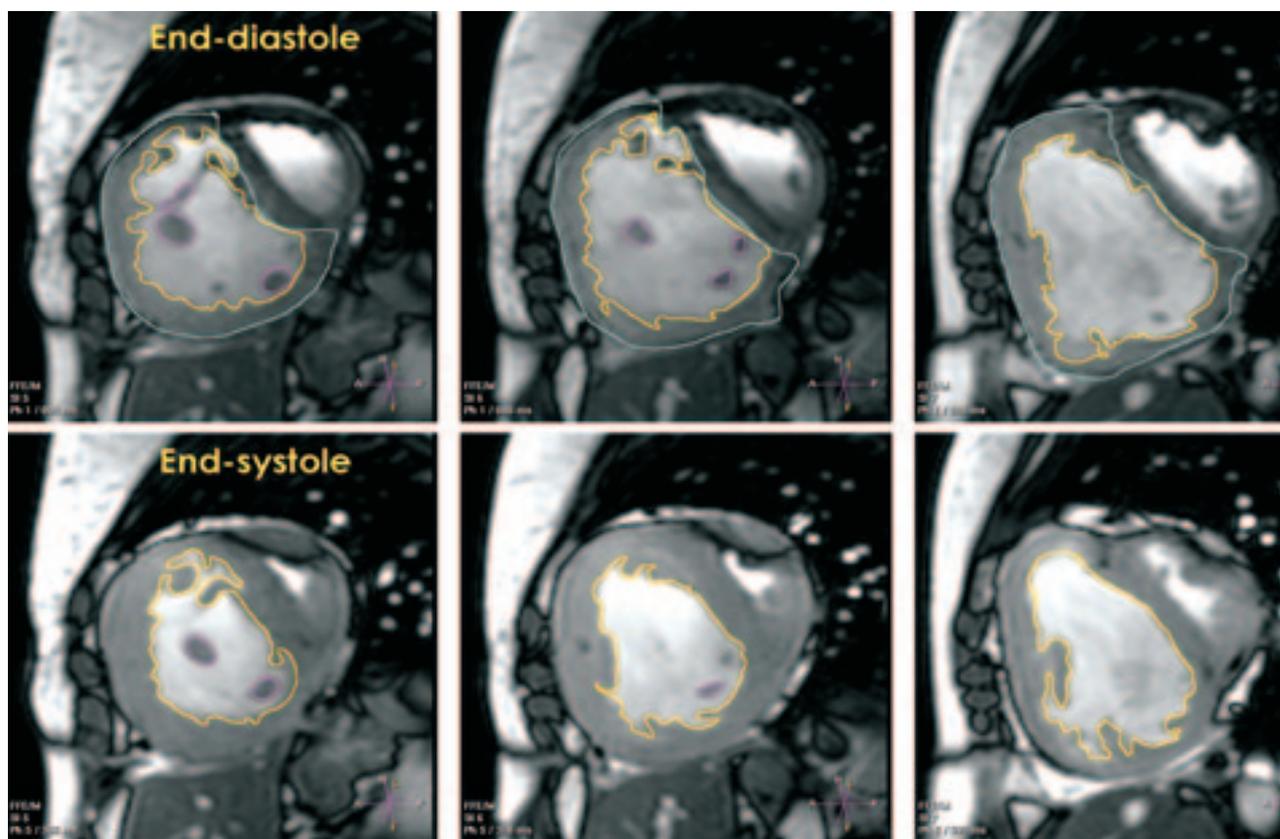


Figure 2. Steady-state free precession cine short-axis images from a patient with severe pulmonary hypertension. Right and left ventricular volumes and mass can be measured from a set of short-axis slices encompassing both ventricles from base to apex. The endocardial borders of the right ventricle are manually traced at end-diastole and end-systole. The epicardial borders are traced in end-diastole, for computation of right ventricular mass. With the slice thickness known, the volumes contained within all the endocardial borders are summed at each heart phase, and the total volume is then computed. To calculate mass, the volume of myocardium contained within the epicardial and endocardial borders is computed and multiplied by an assumed specific gravity of myocardium (1.05 g/ml). This method of volume measurement is independent of cavity shape and is ideal for the right ventricle.

quantitative evaluation of pulmonary blood flow and, although not commonly used at present, they have the potential to contribute greatly to the assessment of suspected pulmonary vascular disease.

In terms of magnetic resonance imaging of the lung per se, this is inherently difficult due to the low proton density and the large number of soft tissue-air interfaces, both of which reduce the amount of emitted signal. However, advances in hardware design and imaging sequences have led to improved evaluation of the lung parenchyma.⁴

Recently, developments in hardware and software have enabled CMR guidance of endovascular catheters under real-time imaging (magnetic resonance fluoroscopy). This CMR approach is a promising tool

for assessing RV contractility in the clinical setting¹³ and quantifying pulmonary vascular resistance more accurately,¹⁴ leading to better treatment of patients with PAH.

In conclusion, CMR is a robust and versatile modality that holds tremendous promise in the evaluation of PAH.

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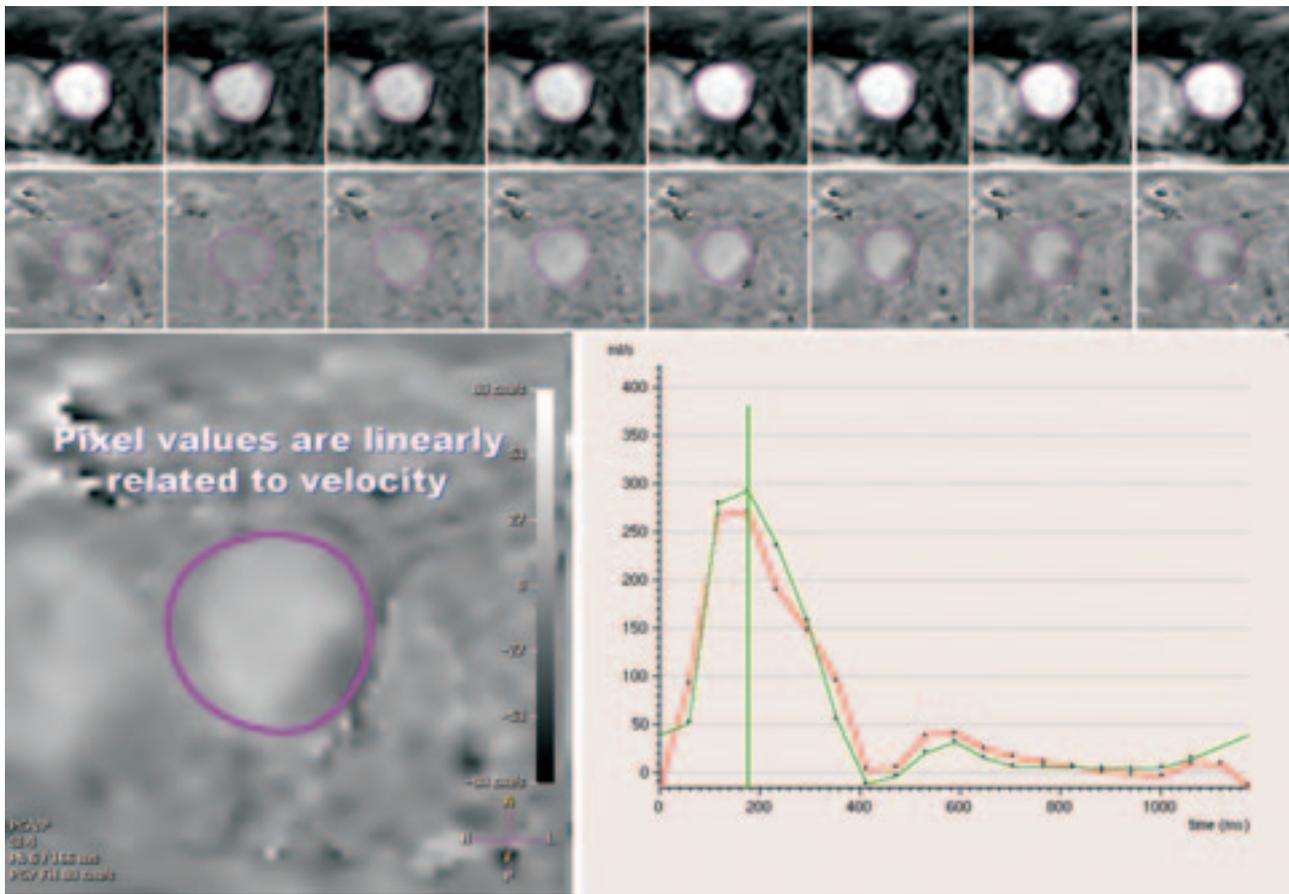


Figure 3. Phase-shift velocity mapping in a plane transecting the pulmonary trunk. The principle underlying this technique is based on the phase-shift of the moving protons, which is proportional to blood flow velocity. On the resultant images, pixel values are linearly related to velocity (bottom left). For pulmonary flow measurement, the cross-sectional area of the pulmonary trunk lumen is outlined manually in each cine frame throughout the cardiac cycle, and the mean axially directed velocity is measured within that area (top and middle row). The respective instantaneous flows are then derived from the products of the individual luminal areas and the mean velocities within them. From these data, graphs can be constructed, on which pulmonary flow is plotted against time (bottom right).

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