Accuracy and Internal Consistency of Cardiac Magnetic Resonance Imaging in Measuring Branch Pulmonary Artery Flows in Patients With Conotruncal Anomalies and Branch Pulmonary Artery Stents

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Clinicians use branch pulmonary artery (BPA) blood flow distribution to help determine the need for intervention. Although phase-contrast magnetic resonance (PCMR) flow measurements are accurate, this has never been shown in the vicinity of a BPA ferromagnetic stent (FS) which produces significant susceptibility artifact. We retrospectively reviewed 49 consecutive PCMR studies performed from 2005 to 2012 on patients with repaired conotruncal anomalies and either left (n = 29) or right PA (n = 20) stents. Three methods of measuring the stented BPA flow were compared: (1) main PA (MPA) minus nonstented BPA, (2) direct PCMR of stented BPA away from the artifact, and (3) pulmonary venous flows (ipsilateral to stented BPA and derived pulmonary blood flow ratio from bilateral pulmonary venous flows). Internal consistency was tested with the Student *t* test, linear regression, Bland−Altman analysis, and intraclass correlation (ICC). The mean age was 11.7 ± 6.9 years with 5.8 ± 4.2 years between stent placement and CMR. There was good agreement without significant difference between MPA-derived stented BPA flow (method 1) and direct PCMR of stented BPA (method 2; 41 ± 19% vs 39 ± 19%, p = 0.59; R^2 = 0.84, p <0.001; ICC = 0.96). There was also good agreement between methods 1 and 2 compared to pulmonary venous flows, with the highest correlation occurring between method 2 and ipsilateral pulmonary venous flow (R^2 = 0.90, p <0.001; ICC = 0.97 for MPA-derived−stented BPA flow; R^2 = 0.94, p <0.001; ICC = 0.98 for direct PCMR of stented BPA). Eleven of the 49 patients (22%) underwent interventional catheterization after PCMR. In conclusion, in the vicinity of a BPA FS, accurate measurement of the net fractional pulmonary blood flow ratio is feasible. PCMR adjacent to the stent and ipsilateral pulmonary venous flows provide the most internally consistent data. These data underscore PCMR's utility in managing patients with implanted FS. **(Am J Cardiol 2016;117:1160−1166)**

After repair of Tetralogy of Fallot (ToF) and other related conotruncal anomalies, a substantial portion of patients will have residual branch pulmonary arterial (BPA) stenosis[1−4] which will benefit from BPA stent implantation with the aim of distributing balanced flows to both lungs and optimizing cardiopulmonary efficiency. Over time, these stents are subject to stenosis secondary to in-stent endothelial proliferation or to the growth of the patient relative to the caliber of the stent at the time of implantation. Consequently, there is a need for continued surveillance to determine the timing of future balloon dilatations of the implanted stent. Many of the implanted BPA stents are composed of ferromagnetic materials, which produce localized artifact in the region of the stent during cardiac magnetic resonance (CMR) examinations. These stents are generally considered magnetic resonance (MR) safe, but signal distortion may preclude direct anatomic and phase CMR (PCMR) measurements within the stent. Radionuclide pulmonary scintigraphy has traditionally been used for measuring the net pulmonary blood flow (PBF) distribution in patients with BPA stenosis.[5,6] However, in more recent years, clinicians have turned to PCMR which has been shown to accurately measure PBF[6−8] without the use of ionizing radiation, of particular importance to pediatric age patients. The accuracy of PCMR in the context of an implanted ferromagnetic BPA stent is unknown. We hypothesized that measurement of the stented

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See page 1166 for disclosure information.

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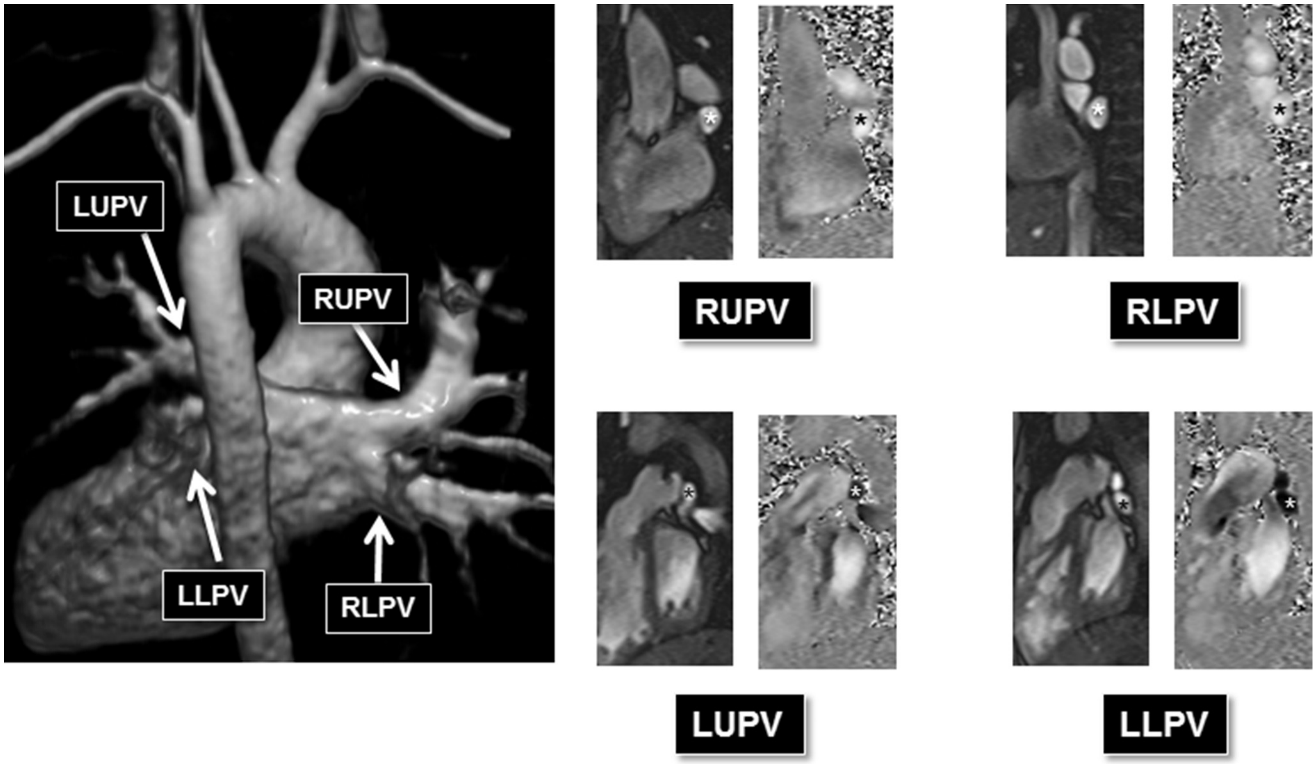

Figure 1. The anatomic locations for acquisition of pulmonary vein PCMR data are shown. Pulmonary veins are indicated by asterisks on the respective through-plane PCMR magnitude and phase images. LLPV = left lower pulmonary vein; LUPV = left upper pulmonary vein; RLPV = right lower pulmonary vein; RUPV = right upper pulmonary vein.

Table 1
Study population

Variable	Total (n=49)
Age (years)	12±7
Diagnoses	
Tetralogy of Fallot	33
Tetralogy of Fallot/pulmonary stenosis	22 of 33
Tetralogy of Fallot/pulmonary atresia	11 of 33
Tetralogy of Fallot/pulmonary atresia with multiple aorto-pulmonary collaterals	2 of 11
Transposition of the great arteries	5
Double outlet right ventricle	1
Truncus arteriosus	7
Other	3
Left pulmonary artery stents	29
Right pulmonary artery stents	20
Number of studies with pulmonary vein data	21

BPA flow could be accomplished in the presence of ferromagnetic stents (FSs).

Methods

We retrospectively reviewed 49 consecutive repaired conotruncal anomalies PCMR and cine MR studies performed from January 2005 to December 2012. All patients underwent either left (n = 29) pulmonary artery (LPA) or right (n = 20) PA (RPA) stainless steel stent placement. Patients with bilateral BPA stents and patients with functional single ventricle were excluded from the study. The investigators had full access to the data and take responsibility for its integrity. All investigators have read and agree to the manuscript as written. The study was approved by the institutional review board.

Our CMR protocol includes an initial steady-state free precession bright blood 3-dimensional static volume set acquired in the axial plane during diastole. Multiplanar reformatting was used for prescribing the optimal imaging plane to acquire segmented PCMR and cine data. Retrospective electrocardiogram-gated through-plane PCMR images were acquired for the main PA (MPA; or conduit in patients with pulmonary atresia) and nonstented BPA in all patients. Where technically feasible, PCMR was acquired immediately proximal or distal to the stent. PCMR measurements were acquired proximal to the stent only if there was adequate length between the MPA and the proximal edge of the stent to allow for a thin slice plane (3.0 to 5.0 mm) as suggested on cine imaging. PCMR measurements distal to the stent were only acquired if there was adequate length between the distal edge of the stent and the upper lobe BPA so that all lung segments supplied by the stented artery could be reliably acquired in a single acquired slice plane. In the rare case of where a single discrete upper lobe BPA had bifurcated, that too was included in the PCMR flow measurement. Our protocol expanded over time to include pulmonary venous flow measurements as an additional means of assessing the PBF distribution (Figure 1). When possible (based on whether all the