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Complex 3D Blood Flow Pathways in Two Cases of Aorta to Right Heart Fistulae: a 4D Flow MRI study

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Abstract

We present an analysis of 3D blood flow in two cases of Sinus of Valsalva to right heart fistulae based on 4D flow MRI. Despite similar underlying pathology, 3D visualization revealed intricate differences in flow patterns connecting the systemic and pulmonary circulation. The cases illustrates the potential of 4D flow MRI to complement the evaluation of complex structural heart disease by assessing complex flow dynamics and providing quantitative information of flow ratios and flow rates.

Keywords

MRI; hemodynamics; 4D flow MRI; fistula

We present two cases of Sinus of Valsalva aneurysms¹ with aorta to right heart fistulae² demonstrating similar underlying pathology but substantial differences in 3D flow characteristics and systemic to pulmonary flow distribution. A 64-year-old male (case 1) was incidentally noted to have a heart murmur. Transesophageal echocardiogram detected a pouch-like structure at the non-coronary Sinus of Valsalva with flow across the structure demonstrating left to right shunting. Cardiac catheterization demonstrated flow from the right Sinus of Valsalva into the right ventricle (RV) suggestive of a aorta to RV fistula. Secondly, a 25-year-old woman (case 2) was evaluated for a lifelong asymptomatic heart murmur that began to worsen during pregnancy. Serial echocardiograms demonstrated a SoV aneurysm that had ruptured into the right ventricular outflow tract with continuous flow through the defect. Post-partum echocardiograms demonstrated left ventricular (LV) dilation, trace aortic regurgitation and mild tricuspid and mitral regurgitation.

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For both cases MRI (1.5T Avanto, Siemens, Germany) was performed and included 2D CINE imaging for the assessment of cardiac function and 2D phase contrast (PC) MRI for flow quantification at the aortic (Qs) and pulmonary (Qp) valves and through the fistula³. To gain further insights into the complexity, directionality and spatial distribution of the blood flow connecting the aorta and right heart through the fistula, time resolved 3D PC MRI with three-directional velocity encoding (4D flow MRI) was obtained with full volumetric coverage of the entire heart and surrounding great vessels (velocity sensitivity = 150 cm/s, spatial/temporal resolution = $2.6 \times 2.6 \times 3.2 \text{ mm}^3 / 38 \text{ ms}$)⁴. Data analysis (EnSight, CEI, USA) included 3D visualization of blood flow using time-resolved 3D path-lines. Retrospective quantification of flow was performed in the aorta and pulmonary artery to calculate Qp:Qs and flow through the fistula from the 4D flow data. The study was approved by the institutional review board and informed consent was obtained from the patients.

Figures 1 and 2 illustrate the anatomic location and shape of the fistula connecting the aorta and right heart (2D CINE MRI) as well as 3D blood flow over two consecutive cardiac cycles. The dynamics and distribution of 3D blood flow pathways directly connecting the aorta and the right ventricle can clearly be appreciated for both cases. In case 1, flow through the fistula reached the RV during the first RR-interval (figure 1A–D) and was further ejected into the pulmonary circulation during the subsequent cardiac cycle (figure 1E,F). In contrast, 3D flow visualization in case 2 clearly demonstrated more substantial fistula to RV flow which was immediately redirected towards the pulmonary outflow tract during a single cardiac cycle (figure 2A, B). A distinct flow channel directly connecting the aorta and pulmonary trunk via the right ventricle is clearly visible (figure 2A, dashed arrow).

Retrospective flow quantification based on 4D flow data confirmed high Qs:Qs (5.3) and fistula flow (64ml/cycle) for case 2 compared to more moderate values for case 1 (Qs:Qs = 1.5, fistula flow = 29ml/cycle).

Sinus of Valsalva aneurysm is a cardiac anomaly, usually congenital in etiology and discovered incidentally on echocardiography¹. Rare complications are aorto-cardiac fistulae, often infective or traumatic in etiology usually secondary to a ruptured SoV aneurysm². Despite similar cardiac anomaly, 3D blood flow visualization revealed intricate differences in flow patterns connecting the systemic and pulmonary circulation. Marked differences in magnitude and timing of flow directly connecting the aorta and pulmonary artery by different pathways through the fistula and right heart were observed.

Retrospective flow quantification based on 4D flow data yielded similar results compared to the standard MR method 2D PC MRI which required the presence of the physician at the scanner to identify the location of the fistula and to determine the precise location of imaging planes for flow analysis. The complexity of the cardiovascular geometry in both cases made 2D imaging plane positioning difficult and lengthened the time the patients had to remain inside the MR system. In contrast, 4D flow MRI offered easy scan prescription (3D volume covering the heart) and may, despite its long scan time of 15–20min, be advantageous in such cases with complex cardiovascular anatomy since the locations for flow analysis can be identified retrospectively after the MR exam.

4D flow MRI may help to complement the evaluation of complex structural heart disease by providing a visual three-dimensional illustration of complex flow dynamics while providing similar quantitative diagnostic information compared to the reference standard. While 4D flow did not change the management of these patients, 3D flow visualization may be a useful tool helping for surgical planning and to evaluate the postoperative hemodynamic status.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Case 1, patient with mild Ao-RV fistula flow ($Q_p:Q_s = 1.5$). Continuous flow from the ascending aorta (AAo) to the right ventricle (RV) can be observed throughout the cardiac cycle. During systole (A, B) a distinct fistula flow channel from the AAo to the RV is evident (white arrow). During early diastole (C), flow originating at the fistula spits into 2 flow channels to the RA and into the right ventricle (RV) through the opened tricuspid valve. During late diastole (D), aortic valve insufficiency results in marked retrograde flow in the aorta and blood flow through the fistula is predominately directed into the RV. In the subsequent cardiac cycle (E, F), the fistula blood in the RV is ejected into the pulmonary trunk (PT, dashed arrows) while systolic fistula flow continues to leak into the RA (white arrows). See also supplemental video 1.

Figure 2.

Case 2, patient with severe Ao-RV fistula flow ($Q_p:Q_s = 5.3$). In contrast to case 1, flow originating at the fistula directly connects the ascending aorta (AAo) with the right ventricle (RV) and pulmonary outflow tract. During early systole (A) a marked flow channel directly redirecting flow from the AAo through the RV to the pulmonary trunk (PT) (dashed arrow) is clearly visible. The AAo to PT flow channel persists into late systole (B) but changes its orientation towards the RV during diastole (C, dashed arrow) and is accompanied by aortic retrograde flow and valve insufficiency (C, solid arrows). In the following cardiac cycle (D) the fistula flow is again redirected towards the pulmonary outflow tract. See also supplemental video 2.