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Visualization of Vascular Hemodynamics in a Case of a Large Patent Ductus Arteriosus Using Flow Sensitive 3D CMR at 3T

Alex Frydrychowicz, MD,[1] Thorsten A. Bley, MD,[1] Sven Dittrich, MD,[2] Jürgen Hennig, PhD,[3] Mathias Langer, MD, MBA,[1] and **Michael Markl, PhD[3]**

Department of Diagnostic Radiology, University Hospital Freiburg, Freiburg, Germany[1]
Pediatric Cardiology, University Hospital Freiburg, Freiburg, Germany[2]
Department of Diagnostic Radiology, Medical Physics, University Hospital Freiburg, Freiburg, Germany[3]

ABSTRACT

Comprehensive flow velocity acquisition based on time-resolved three-dimensional phase-contrast CMR with three-directional velocity encoding was employed to assess arterial hemodynamics in a patient with a large patent ductus arteriosus with Eisenmenger's physiology. Computer-aided visualization of blood flow characteristics provided detailed information about temporal and spatial distribution of left and right ventricular outflow. Main findings included the depiction of the location and extent of two flow channels for systolic aortic filling, a relatively large amount of pulmonary artery to aortic flow confirming Eisenmenger's physiology, and a slight phase difference between right and left ventricular ejection. These results illustrate the feasibility of flow sensitive 3D CMR at 3T in relation to a potential field of clinical application such as congenital heart disease with abnormal vascular connections or shunt flow.

[Supplementary materials are available for this article. Go to the publisher's online edition of *Journal of Cardiovascular Magnetic Resonance* for two free supplemental movie clips.]

INTRODUCTION

The intrinsic sensitivity of cardiovascular magnetic resonance (CMR) to flow (1–3), its ability to acquire anatomical and flow data within a 3D volume, and the benefits of imaging at 3T (improved SNR [4,5]) were exploited to acquire both blood flow characteristics and morphological information in a patient with a large patent ductus arteriosus (PDA) in addition to routine diagnostic follow-up. Three-dimensional software tools were employed to visualize and quantify spatial and temporal distribution of the acquired blood flow velocities (6).

METHODS

Measurements were performed on a 3T-MR-system (TRIO, Siemens Medical Solutions, Erlangen, Germany) using a ECG gated and respiration controlled rf-spoiled gradient echo sequence with interleaved 3-directional velocity encoding (6–9). Imaging parameters were: velocity sensitivity = 150cm/s, spatial resolution 2.1 × 3.2 × 3.5mm^3 in a sagittal oblique 3D volume with rectangular FOV = 400 × 300 mm^2, flip angle = 15°, TE = 3.5 ms, TR = 6.1 ms, band width = 480 Hz/pixel.

Data evaluation was performed using a commercially available software package (EnSight, CEI, Apex, North Carolina, USA) and included blood flow visualization as 3D stream-lines (traces along the measured blood flow velocities for a given time frame), time-resolved 3D particle traces (virtual particles illustrating spatial and temporal evolution of blood flow), and time-resolved vector graphs (10).

CASE REPORT

Findings in a 39-year-old female patient, who was scheduled for regular follow-up of a patent ductus arteriosus (PDA), chronic pulmonary hypertension and chronic heart failure NYHA III, are presented. Swelling edema of the lower extremities coincided with the termination of therapy (aspirin and the ET-1 receptor antagonist Bosentan). Due to a chronic right-to-left shunt, mild cyanosis and digital clubbing were observed. Contrast-enhanced CMR-angiography (CE-MRA) (11) performed for routine follow-up revealed a large PDA diameter

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Correspondence to:
Dr. Med. Alex Peter Frydrychowicz
University Hospital Freiburg
Department of Diagnostic Radiology
Hugstetter Str. 55
79106 Freiburg, Germany
tel: +49-761-270-3802; fax: +49-761-270-3838;
email: alex.frydrychowicz@uniklinik-freiburg.de

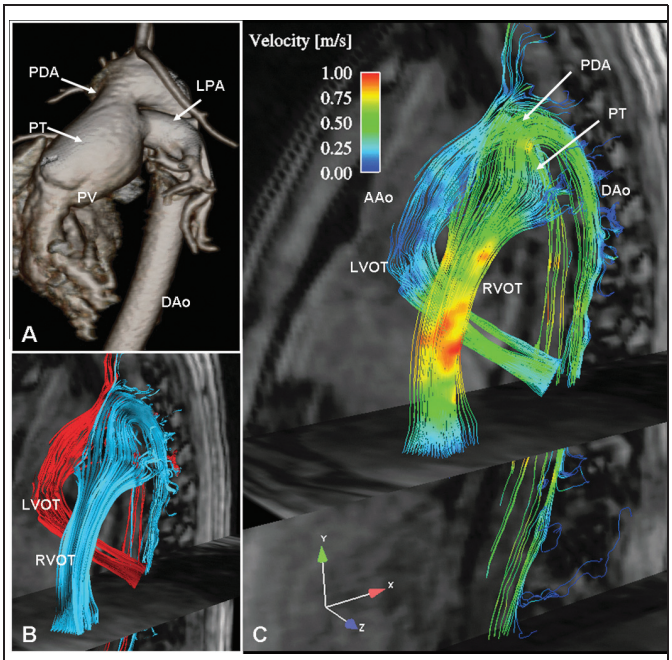

Figure 1. A) Contrast enhanced CMR-angiography at 1.5T and volume rendered images of a large patent ductus arteriosus (PDA) between the dilated pulmonary trunk (PT) and the aorta. (PV = pulmonary valve, DAo = descending aorta, LPA = left pulmonary artery. B) Three-dimensional stream-lines originating from the left (LVOT, red) and from the right ventricular outflow tract (RVOT, blue). C) Color-coded 3D stream-lines demonstrating differences in flow velocities of the left and right outflow tract with the right ventricle predominantly contributing to aortic filling.

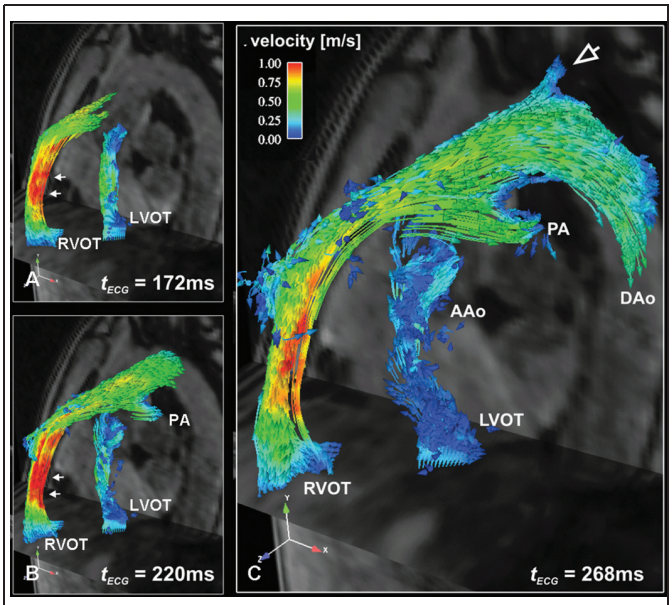

Figure 2. Time-resolved 3D particle traces for three successive systolic time frames. Particle traces were emitted at the beginning of the cardiac cycle in regions corresponding to the left (LVOT) and right (RVOT) outflow tract. Temporal evolution during systole indicates substantial differences in blood flow, cardiac output and aortic filling if the left and right side are compared. These findings can also be appreciated in the supplemental movie file 1 online. Reduced contribution of the left ventricular outflow to aortic filling can clearly be appreciated and correlate with reduced peak velocities in comparison to the right ventricular outflow.

(2.2 cm), a dilated pulmonary trunk (Fig. 1A) and hypertrophy of the right ventricle. For the additional assessment of blood flow characteristics, flow sensitive 3D CMR imaging and subsequent blood flow visualization was performed (Figs. 1 and 2). Selection of different colors in Fig. 1B for 3D stream-lines originating from the left ventricle (red, LVOT) and the right ventricle (blue, RVOT) clearly depicts the location and extent of two flow channels for systolic aortic filling. Note the widening of the blue flow channel just before the connection with the aortic arch, indicating the enlarged pulmonary trunk. Color coding according to the measured flow velocities (Fig. 1C) added information about blood flow differences and revealed substantially higher right ventricular flow if compared to left ventricular outflow.

Time-resolved 3D particle traces (Fig. 2) illustrate systolic filling, originating from left (LVOT) and right (RVOT) ventricular outflow tracts. The direction of blood flow (arrow heads) clearly demonstrates the flow direction (right ventricle to aorta) associated with Eisenmenger's physiology. Consistent with Figure 1C, considerably higher blood flow velocities are visible for right ventricular outflow (Fig. 2A and 2B, yellow and red color, solid white arrows), resulting in rapid filling of the ductus arteriosus and aortic arch. During end-systole (Fig. 2C), initial filling of the pulmonary artery (PA) as well as supra-aortic branches (open white arrow) and distal descending aorta (DAo) can be appreciated. In contrast, left ventricular outflow exhibits relatively low blood flow velocities (green to blue color) resulting in reduced filling of the ascending aorta (AAo). The dynamics of aortic filling are also depicted in the supplemental movie files 1 and 2. Movie 2 shows time-resolved vector graphs in planes transecting the ascending aorta and the right ventricular outflow tract for detailed qualitative evaluation of local blood flow profiles. In addition to substantial difference in blood flow amplitudes, phase differences between right and left ventricular ejection can be appreciated.

DISCUSSION

The presented findings in a patient with a large patent PDA with Eisenmenger's physiology illustrates the potential of the presented method to provide a comprehensive overview over blood flow patterns for the assessment of the temporal and spatial distribution of pathological hemodynamics in 3D. Flow sensitive 3D CMR was successfully used to demonstrate the existence of a right-to-left shunt and associated blood flow characteristics such as the substantial blood flow directed from the right ventricle through the PDA in the aorta.

Note that the stream-line and particle trace visualization may be visually misinterpreted to over- or understate differences in blood flow. However, color coding in both stream-lines and particle traces is directly linked to measured local blood flow velocity

magnitude and can thus be used to identify regional differences in blood flow.

A major drawback of the present methods is related to the time-consuming post-processing and data analysis, which to date limits its application in a routine clinical setting. However, the possibility for retrospective data processing within a 3D volume covering the entire vasculature of interest may help to identify unexpected hemodynamic consequences of pathologies. In addition, simplification of post-processing tools and thus more intuitive data evaluation may be required to establish the clinical usefulness 3D CMR flow analysis.

Obviously, in the presented case, a similar diagnosis could have been made by adequate slice positioning and routine breath-held 2D CINE velocity mapping (12). Nevertheless, initial findings as presented in this case are promising and point towards the future potential of flow-sensitive 3D CMR for the detailed analysis of vascular hemodynamics.

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