Flow Assessment over All Heart Valves Simultaneously using 3D Velocity-Encoded MRI with Retrospective Valve Tracking

J. J. Westenberg[1], S. D. Roes[1], S. Hammer[2], P. J. van den Boogaard[1], N. Ajmone Marsan[3], J. J. Bax[3], J. H. Reiber[1], A. de Roos[1], and R. J. van der Geest[1]

[1]Radiology, Leiden University Medical Center, Leiden, Netherlands, [2]Internal Medicine, Leiden University Medical Center, Leiden, Netherlands, [3]Cardiology, Leiden University Medical Center, Leiden, Netherlands

Introduction

Sequential flow assessment at each of the four heart valves using the conventional 2-dimensional (2D) 1-directional (1-dir) through-plane velocity-encoded (VE) MRI-method not only extents imaging time when flow through the valves needs to be studied, but also shows low agreement in net flow volumes between the four valves. The application of 1-dir 2D VE MRI for valvular flow is limited because the acquisition plane remains fixed during the whole cardiac cycle and cannot be adapted to the cardiac motion or to the direction of a regurgitant jet.

Purpose

Three-dimensional (3D) 3-directional (3-dir) VE MRI is introduced for assessing the 3D flow velocity field during the cardiac cycle at the basal level of heart, including the left and right ventricular outflow tract. Reformatting of each of the valvular planes during offline analysis (i.e., retrospective valve tracking) is performed to quantify the flow through all heart valves simultaneously. This technique is applied in volunteers without valve regurgitation and in patients with valve regurgitation.

Material and Methods

MRI was performed on a 1.5T Gyroscan ACS/NT15 MRI (Philips, Best, The Netherlands). 3D 3-dir VE MRI was used with the following scan parameters: 3D volume scan with slab thickness 48 mm, acquisition voxel size 2.9×3.8×4.0 mm^3, TR=14ms, TE=3.3ms, FOV 370mm, flip angle 10º, velocity encoding with sensitivity 150 cm/s in all three directions, 30 phases reconstructed during one average cardiac cycle, Echo Planar Imaging with EPI-factor 5. Scanning was performed during free-breathing. During planning, caution was taken to include all four heart valves during the whole acquisition inside the 3D volume slab (Figure 1).

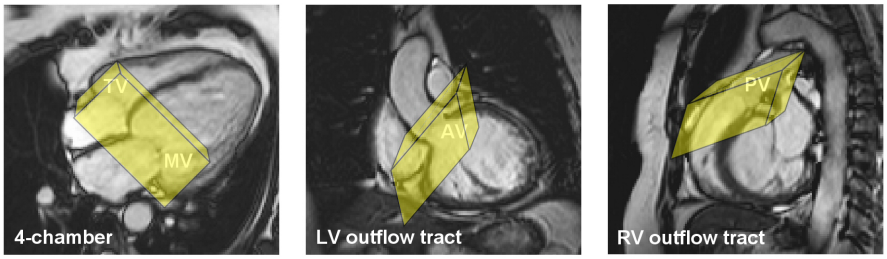

Figure 1. Planning of volume slab for 3D 3-dir VE MRI, with all four heart valves inside the slab during the whole cardiac cycle (LV: left ventricle; RV: right ventricle; MV: mitral valve; TV: tricuspid valve; AV: aortic valve; PV: pulmonary valve).

From the 3D 3-dir VE MRI-data, the 3D velocity vector field was constructed. The through-plane velocity for each valve plane was reformatted offline using two orthogonal reformat-guides per plane (i.e., for mitral valve (MV): 2- and 4-chamber of the left ventricle (LV); for tricuspid valve (TV): 2- and 4-chamber of the right ventricle (RV); for aortic valve (AV): two orthogonal views of the LV outflow tract; for pulmonary valve (PV): two orthogonal views of the RV outflow tract.

In the reformatted through-plane velocity images, the trans-valvular flow area is manually segmented in each cardiac phase. Background correction (taking both through-plane motion correction (1) and correction for local phase offset errors (2) into account) is performed as follows: in each cardiac phase of the velocity images, a region-of-interest (ROI) is placed inside the myocardium near the trans-valvular flow area. The background ROI for assessment of the AV-flow was placed in the LV anterior wall, for PV-flow in the septum, for MV-flow in the lateral LV wall and for TV-flow in the lateral RV wall. In order to obtain the flow in each phase, the average velocity measured over the annulus was first subtracted from the average velocity measured in this background ROI, and then multiplied with the area of the annulus. In 16 volunteers (mean age 20±8 years) without valve regurgitation and in 29 patients (mean age 61±13 years) with singular or multiple valve regurgitation proven on echocardiography, the flow was assessed through all four valves. Regurgitation was quantified. Intraclass correlation (ICC) for absolute agreement between the net flow volumes per valve was examined and differences in net flow volumes were studied.

Results

Flow acquisition was successful in all volunteers and patients. No distortion or susceptibility artifacts caused by EPI were seen in the data. Mean scan time for 3D 3-dir VE MRI was 4.2±0.8 min at a mean heart rate of 67±12 beats per minute. Retrospective valve tracking in offline analysis and manual segmentation took approximately 10-15 minutes for each valve. The comparison of the net flow volumes between the four heart valves for volunteers and patients is summarized in Table 1. In volunteers, comparison of the net flow volumes through the four valves showed strong correlation with only small bias and small confidence intervals. In patients, also strong correlation between the net flow volumes per valve were found with no significant biases. Mean regurgitant fraction for MV=14±9% (range: 4-32%), TV=12±7% (range: 2-25%), AV=3±4% (range: 0-19%) and PV=3±3% (range: 0-10%).

		MV-AV	MV-TV	MV-PV	TV-AV	TV-PV	PV-AV
Volunteers (n=16)	**ICC**	0.97	0.99	0.97	0.98	0.97	0.98
	Mean difference ± SD	4 ± 6 ml	-1 ± 5 ml	5 ± 6 ml	4 ± 5 ml	6 ± 6 ml	-1 ± 6 ml
	p-value t-test	0.01	0.70	<0.001	0.003	0.005	0.34
	Confidence interval	-9 – 16 ml	-11 – 10 ml	-6 – 16 ml	-6 – 13 ml	-6 – 17 ml	-13 – 10 ml
Patients (n=29)	**ICC**	0.97	0.98	0.94	0.91	0.92	0.98
	Mean difference ± SD	1 ± 7 ml	0.3 ± 4 ml	0.1 ± 10 ml	0.5 ± 8 ml	-0.2 ± 11 ml	0.6 ± 6 ml
	p-value t-test	0.56	0.70	0.96	0.75	0.92	0.55
	Confidence interval	-13 – 14 ml	-8 – 9 ml	-19 – 19 ml	-5 – 16 ml	-22 – 22 ml	-11 – 13 ml

Table 1. Comparison of the net flow volumes between the four heart valves for volunteers and patients. MV: Mitral Valve; TV: Tricuspid Valve; AV: Aortic Valve; PV: Pulmonary Valve; ICC: intraclass correlation coefficient for absolute agreement.

Conclusion

Three-dimensional three-directional velocity-encoded MRI in combination with retrospective valve tracking in offline analysis will provide the true trans-valvular flow for all four heart valves simultaneously in less than 5 minutes scan time. The net flow volumes show good agreement between the valves. Regurgitation and forward flow can be quantified accurately.

References

1. Kayser HW et al. J Magn Reson Imaging 1997;7:669-673.
2. Chernobelsky A et al. J Cardiovasc Magn Reson 2007;9:681-685.