Quantification of Left-to-Right Shunt in Pediatric Patients

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Introduction

Shunt quantification is essential in the management of congenital heart disease. Blood flow can be determined noninvasively by phase-contrast cine magnetic resonance imaging (PC-MRI) in adults as validated in numerous studies (1-5). However, little is known about the feasibility of PC-MRI in children, where higher peak velocities and blood pulsation rates may hamper velocity quantification (6,7). We therefore sought to evaluate pulmonary, aortic and systemic venous flows by PC-MRI in pediatric patients with congenital heart disease.

Methods

50 children with a significant left-to-right shunt were enrolled (mean age 6.2±3.2 years, range 1.1-17.7, 28 female), 40 patients with secundum atrial septal defect, 3 partial anomalous pulmonary venous return (PAPVR), 4 sinus venosus defect with PAPVR and 3 patients with ventricular septal defect (VSD). 7 children with congenital heart disease but no cardiac shunts were analysed for their Qp/Qs ratio by PC-MRI (mean age 7.9±4.4 years, range 1.3-13.5, 4 male). Each patient underwent MRI examination (1.5 T whole body system, PMS, ACS-NT, R 6.2, gradient slew rate 105 T/m/s, 23 mT/m) to measure through-plane flow in the ascending aorta and pulmonary artery and in 37 patients also in the superior and inferior vena cava using a flow-sensitive gradient-echo pulse sequence: TE 6 ms, TR 20 ms, FOV 250-300 mm, matrix 128*96, flip-angle 30°, retrospective gating to include end-diastole flow, velocity encoded values 200-300 cm/s for arteries, 150 cm/sec for veins. Phase offsets from residual eddy current effects were corrected by use of an algorithm provided by the manufacturer working as a magnitude-weighted, spatial low-pass filter. Three measurements were acquired in each location, imaging time for each measurement was 2.2 to 3 minutes with 15-20 reconstructed frames per average cardiac cycle The body coil was utilized for both signal transmission and detection, since image reconstruction time was too long using a phased-array cardiac coil.

Image data analysis was performed off-line using a computer algorithm for semi-automatical vessel border detection developed by P. Barth, allowing for flow calculations to be completed in a single vessel within 1-2 minutes.

For in vitro validation of our PC-MRI protocol we used a two-roller pump from a heart-lung-machine delivering 5 different flow rates over a range of 0.65 to 2.63 l/min. Each measurement was repeated twice and controlled by stop watch and a graded cylinder. MRI studies were followed by invasive oximetry (Fick formula) during cardiac catheterization. Statistics: 2-variable linear regression analysis for in vitro results. Analysis of Bland and Altman (8) to determine (a) PC-MRI interobserver variability and assess the agreement between (b) Qp/Qs by PC-MRI and oximetry, (c) systemic venous and aortic flow by PC-MRI.

Results

MRI and catheterization studies were well tolerated. In seven children with congenital heart disease but no cardiac shunting, Qp/Qs by PC-MRI was 1.02 (SD ±0.06). In the 50 children with an atrial or ventricular level shunt, the ratio of the blood flow rate in the pulmonary artery and the ascending aorta (Qp/Qs) as determined by PC-MRI was compared with Qp/Qs by oximetry. There was a difference of 2% and a range of -20% to +26% (limits of agreement, mean ±2SD). No difference between systemic venous and aortic flow volume was found, with a range of -17% to +20% (n=37). The mean difference between three repeated PC-MRI measurements in each location was 5.3% (SD ±4.0%, n=522 flow data sets), demonstrating good precision. The PC-MRI interobserver variability was low: Mean difference 0.2 ml, range –2.8 to +3.2 ml (mean±2SD). PC-MRI flow phantom experiments showed a strong correlation between PC-MRI and manually performed measurements (y=0.075+0.915x, r=1.000, p<0.001), demonstrating a high level of accuracy in vitro.

Discussion

In children higher rates of blood pulsation, flow acceleration and respiration are present along with higher peak flow velocities and smaller vessels (6). In our validation study, we used a moderately short TE of 6 ms, recommended to limit intravoxel phase dispersion and sensitivity to higher order motion components (7,9). The relatively large voxel size of 2*2.5*5mm3 was considered still small enough to avoid significant partial volume effects while ensuring a good SNR for computer-based vessel border detection. Scan time was kept to a minimum to allow repeated measurements in each location within a resonable total imaging time. We did not use the maximum gradient strength, since otherwise a substantial increase of non-flow related phase-shifts was observed both in vivo and in vitro, most likely from residual eddy current effects. Comparing Qp/Qs by PC-MRI and oximetry, we found a fairly good agreement, well acceptable for clinical purposes. In the 7 children with congenital heart disease but no shunts, Qp/Qs values by PC-MRI were very close to unity, confirming results of others (10) demonstrating the ability of PC-MRI to exclude significant shunting in children. Flow volume data from the superior and inferior vena cava in 37 children with normal venous connections served as an internal reference for aortic flow rates by PC-MRI. Agreement of venous with aortic flow was acceptable, as was the agreement of the ratio of pulmonary and systemic venous flow to Qp/Qs by oximetry. In children with congenital heart disease, determination of Qp/Qs and quantification of systemic venous flow by use of a conventional PC-MRI pulse sequence is safe, accurate and reliable as compared with oximetry.

References

1. Hundley WG, Li HF, Lange RA, et al. Assessment of left-to-right intracardiac shunting by velocity-encoded, phase-difference magnetic resonance imaging. A comparison with oximetric and indicator dilution techniques. Circulation. 1995;91:2955-60.

2. Mohiaddin RH, Underwood R, Romeira L, et al. Comparison between cine magnetic resonance velocity mapping and first-pass radionuclide angiocardiography for quantitating intracardiac shunts. Am J Cardiol. 1995;75:529-32.

3. Arheden H, Holmqvist C, Thilen U, et al. Left-to-right cardiac shunts: comparison of measurements obtained with MR velocity mapping and with radionuclide angiography. Radiology. 1999;211:453-8.

4. Firmin DN, Nayler GL, Klipstein RH, et al. In vivo validation of MR velocity imaging. J Comput Assist Tomogr. 1987;11:751-6.

5. Van Rossum AC, Sprenger M, Visser FC, et al. An in vivo validation of quantitative blood flow imaging in arteries and veins using magnetic resonance phase-shift techniques. Eur Heart J. 1991;12:117-26.

6. Stahlberg F, Sondergaard L, Thomsen C. MR flow quantification with cardiovascular applications: a short overview. Acta Paediatr Suppl. 1995;410:49-56.

7. Rebergen SA, van der Wall EE, Doornbos J, et al. Magnetic resonance measurement of velocity and flow: technique, validation, and cardiovascular applications. Am Heart J. 1993;126:1439-56.

8. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1:307-10.

9. Stahlberg F, Thomsen C, Sondergaard L, et al. Pulse sequence design for MR velocity mapping of complex flow: notes on the necessity of low echo times. Magn Reson Imaging. 1994;12:1255-62.

10. Powell AJ, Maier SE, Chung T, et al. Phase-Velocity Cine Magnetic Resonance Imaging Measurement of Pulsatile Blood Flow in Children and Young Adults: In Vitro and In Vivo Validation. Pediatr Cardiol. 2000;21:104-110 [Record as supplied by publisher].