NOVEL REAL-TIME PC-MRI TECHNIQUE FOR ACCURATE SINGLE HEARTBEAT EVALUATION OF PULMONARY-TO-SYSTEMIC FLOW RATIOS USING AN INTERLEAVED TWO-SLICE ACQUISITION SCHEME

H-Y. Lin[1,2], S. B. King[1], Y. Ding[3], D. S. Jassal[2], P. Gervai[1], E. McKenzie-Matwiy[1], O. P. Simonetti[3], B. Tomanek[1], and G. Tian[1]

[1]Institute for Biodiagnostics, National Research Council Canada, Winnipeg, Manitoba, Canada, [2]Radiology, University of Manitoba, Winnipeg, Manitoba, Canada, [3]Internal Medicine, The Ohio State University, Columbus, Ohio, United States

OBJECTIVE: To develop and demonstrate a novel phase-contrast shared velocity encoding (SVE) technique using an interleaved two-slice acquisition scheme for accurate, single heartbeat, evaluation of pulmonary-to-systemic flow ratio (Qp/Qs).

INTRODUCTION: Ventricular and atrial septal defects are among the most common congenital heart defects in both children and adults. Noninvasive quantification of the flow ratio in the pulmonary (Qp) and systemic circulation (Qs) is important to diagnose and evaluate the severity of left-to-right or right-to-left shunting [1]. Current MRI flow measurements are based on breath-hold, ECG-gated, segmented phase-contrast MRI (PC-MRI). Unfortunately, this method requires reliable cardiac-gating, regular heart rhythm, and either respiratory-gating, or breath-holding; these requirements can be unachievable in pediatric, aged, or severely ill patients. Rapid, real-time PC-MRI techniques enable characterization of left-right shunt ratio independent of patient's cooperation and physiological conditions [2,3]. Existing techniques, however, rely on separate acquisitions of two cross-sectional images, one of the main pulmonary artery and one of the aorta, separately, for comparative quantification of flow volume in the pulmonary and systemic circulations. However, the the shunt ratio (Qp/Qs) measurement can be altered by changes in the patient's physiological status between the two flow scans (~ 2-5mins), including variability of breathing pattern, inspiratory vs. expiratory breath-hold, heart rate and anxiety level. In this study, we developed a novel, interleaved, real-time SVE technique that acquires the results both Qp and Qs simultaneously from each heartbeat, eliminating the potential mismatch of Qp and Qs acquired from different heartbeats, different breath-holds, or under different physiological conditions.

METHODS: Background phase subtraction from a pair of positive (+) and negative (-) velocity encodings is commonly used to eliminate undesired phase bias caused by a wide spectrum of system imperfections. SVE is a novel phase-velocity reconstruction algorithm, using a sliding window for phase subtraction on encoding pairs one frame at a time (i.e., [+ -], [- +], [+ -]) instead of two frames at a time as performed in conventional PC-MRI (i.e., [+ -], [+ -]). The SVE method yields twice the effective temporal resolution in real-time flow quantification and makes it feasible to measure shunt ratio in a single heartbeat by interleaving slice acquisitions on a frame-by-frame basis. All MRI experiments were performed on a 3.0 Tesla scanner (Trio, Siemens Healthcare, Erlangen, Germany) with phased-array cardiac coil matrix. In this study, we recruited six healthy volunteers with no history of cardiovascular disease to evaluate the Qp/Qs ratio. Quantitative evaluation of the Qp/Qs ratio is based on the measurement of flow volume in the pulmonary and systematic circulations using. Through-plane blood flow measurements using the both the conventional segmented PC-MRI and the real-time interleaved SVE techniques were performed in: (i) a slice perpendicular to a pulmonary artery (PA) between the pulmonary valve and PA bifurcation and (ii) a slice perpendicular to the aorta just above the aortic valve, avoiding the aortic valve itself. In order to simulate spontaneous physiological variation between MRI scans, the subjects were instructed to switch breathing conditions between normal breathing and Valsalva maneuver [4] via the intercom system. In conventional PC-MRI, we measured pulmonary flow volume during normal breathing; while aortic flow was measured during Valsalva maneuver. Real-time flow scans were performed for approximate 20 sec under similar breathing control instruction, i.e., 10 sec. of normal breathing followed by 10 sec. of Valsalva maneuver, with acquisition of pulmonary and aortic slices interleaved frame-by-frame. Conventional segmented PC-MRI acquisition parameters were: matrix=192x108, spatial resolution=2.3x3.1mm^2, GRAPPA acceleration=2, and Venc=150cm/s, TE/TR/Temporal Res.=3.5/12.8/38.4ms, averages= 2. Real-time acquisition parameters were: matrix=160x88, spatial resolution=2.6x3.4mm^2, GRAPPA acceleration=4, echo-train-length=11, TE/TR/Temporal Res.=3.6/12.8/102.8 ms, echo spacing=0.57ms, binomial 1-1 water excitation pulse was used to eliminate off-frequency artifacts from adipose tissue with reasonable increase in TE and TR.

RESULTS: Magnitude and phase-velocity mapping using real-time SVE and interleaved two-slice acquisition on the pulmonary and the systematic circulations from one healthy volunteer are shown in Figure 1. Magnitude images (upper panel in Fig. 1) clearly illustrate vascular anatomy facilitating ROI placement on the main pulmonary artery (Fig. 1a) and the ascending aorta (Fig. 1b). Pulmonary flow volume during normal breathing was measured as 4.25±1.2 (L/min) using conventional segmented PC-MRI, and 4.21±0.9 (L/min) using the real-time SVE technique; this difference was insignificant despite the reduced spatial and temporal resolution of the real-time acquisition. The Qp/Qs ratio as calculated from the segmented PC-MRI in the whole study group was 1.38±0.12 (mean ± SD), suggesting that shunt ratio was significantly affected by the difference in physiological conditions caused by Valsalva maneuver vs. free-breathing. The real-time interleaved technique resulted in Qp/Qs values of 1.08±0.07 during normal breathing and 1.05±0.06 during Valsalva maneuver, respectively. The shunt ratios (close to 1.0) using the real-time SVE technique illustrate that accurate and reliable Qp/Qs ratio measurements can be made without being affected by physiological variability between scans.

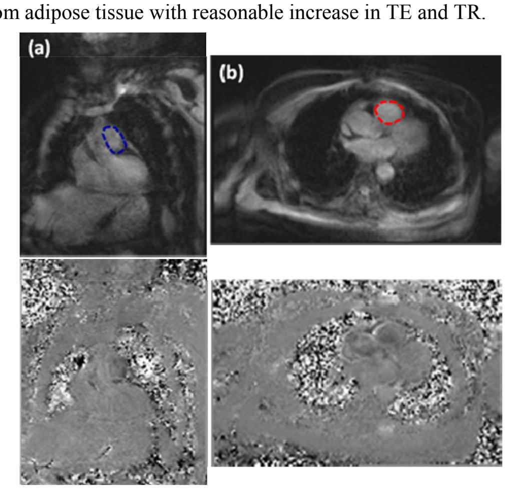

Figure 1. Magnitude and velocity mapping from one out of six subjects using real-time PC-MRI with SVE reconstruction on (a) pulmonary and (b) systematic circulation. Magnitude images offer the capability to depict ROI on main pulmonary artery (ROI in blue) and ascending aorta (ROI in red) to analyze flow volumes and shunt ratios.

CONCLUSIONS: We have demonstrated that accurate measurement of Qp/Qs can be achieved using the proposed real-time, slice-interleaved, acquisition scheme with SVE reconstruction. These preliminary volunteer results illustrate the potential of the proposed method to accurately and reliably diagnose congenital septal defects without influence from short-term variability in physiological conditions.

REFERENCE: [1] Debl, K *et al*, *Br J Radiol*. 2009, 82:386-91 [2] Beerbaum, P *et al*, *Circulation* 2001, 103:2476-82 [3] Lin, HY *et al*, *J of Cardio. Magn. Reson.* 2009, 11:O81 [4] Paulev, P *et al*, *Scand J Clin Lab Invest* 1968, 22:115-23