Noninvasive estimation of pulmonary vascular resistance with 4D flow-sensitive MRI in a canine model of acute pulmonary arterial hypertension

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BACKGROUND: Pulmonary arterial hypertension (PAH) is a fatal disease characterized by a progressive increase in pulmonary vascular resistance (PVR) that ultimately leads to right ventricular (RV) failure [1]. PVR is derived from invasive measurements, using right heart catheterization (RHC), from the ratio of the pulmonary pressure gradient to pulmonary flow ($PVR=\nabla P/Q_P$). Doppler echocardiography is frequently used clinically to noninvasively estimate PVR from the ratio of the peak tricuspid regurgitation velocity (TRV) to the velocity time integral in the right ventricular outflow tract (VTI_{RVOT}) [2]. In patients with PAH, MRI is increasingly used to assess RV volumes and function using breath-hold CINE bSSFP sequences. The ability to determine PVR from MRI would enable a more complete characterization of RV and pulmonary artery (PA) interactions from a single examination. Furthermore, coupled with volumetric flow-sensitive imaging, which includes determination of Q_P, knowledge of PVR could then be used to calculate ∇P noninvasively as well. The purpose of this study was to estimate PVR from TRV/VTI_{RVOT} using a 4D flow-sensitive MRI sequence (PC VIPR – Phase Contrast Vastly undersampled Isotropic Projection Reconstruction) [3] with high spatial and temporal resolution. We hypothesized that differences in PVR between PC VIPR and RHC would not be statistically significant.

METHODS: After IACUC approval, six adult female beagles were induced with propofol and maintained under anesthesia with isoflurane. MRI measurements were performed prior to and following induction of acute PAH by injecting micro-beads (150-500μm) into the right atrium and ventricle. MRI studies were performed on a 3.0T clinical system (Discovery 750, GE Healthcare, Waukesha, WI). ***PC VIPR*** parameters were FOV: 32x32x22cm, readout=256, TR/TE=6.7/2.4, acquired spatial resolution=1.3mm isotropic. PC VIPR was performed following the administration of 0.1mmol/kg of Gd-based intravenous contrast (gadobenate dimeglumine, Bracco Diagnostics, Inc., Princeton, NJ). Data were reconstructed to 20 time frames for dynamic post-processing using retrospective ECG gating and a temporal filter for view sharing. 2D cutplanes through the RVOT and tricuspid valve (TV) were generated in Ensight (CEI, Apex, NC) and exported for analysis in MATLAB (Figure 1). ***RHC*** was performed immediately following the pre-embolization MRI and immediately prior to post-embolization MRI. PVR, in Woods units (WU) was calculated using the following formula: $PVR_{RHC}=(mPAP-PCWP)/CO$, where mPAP is the mean pulmonary arterial pressure, PCWP is the pulmonary capillary wedge pressure, and CO is the cardiac output. Values are reported as mean ± standard deviation. Linear regression analysis was used to assess the correlation between TRV/VTI_{RVOT} and PVR_{RHC}. A linear regression equation was derived to calculate PVR_{MRI}. The differences between the estimated PVR_{MRI} and measured PVR_{RHC} were assessed using Bland-Altman analysis.

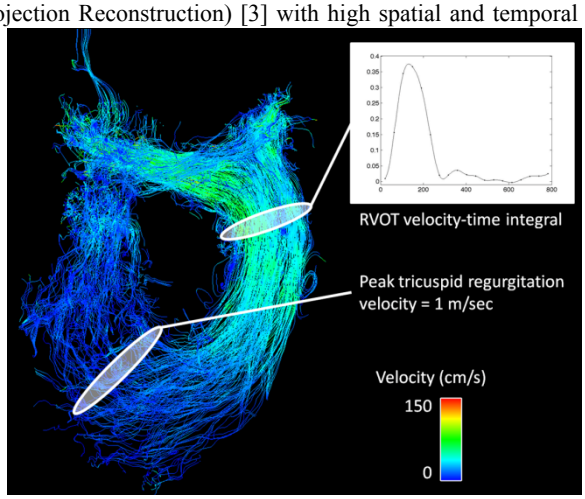

Figure 1. Streamlines from PC VIPR acquisition post-embolization indicating locations of analysis for RVOT velocity-time integral and peak tricuspid regurgitation velocity.

RESULTS: One post-embolization PVR_{RHC} and one pre-embolization TRV/VTI_{RVOT} could not be calculated of technical failures with data acquisition. Therefore, data from 10 paired PVR_{RHC} and TRV/VTI_{RVOT} measurements were used for analysis. PVR_{RHC} values pre- and post-embolization were 2.4±0.8 WU and 8.2±4.4 WU, respectively. The Pearson correlation coefficient (r) between TRV/VTI_{RVOT} and PVR_{RHC} was 0.93 (Figure 2). The equation derived from linear regression was $PVR_{MRI} = 0.44(TRV/VTI_{RVOT}) - 4.73$. Using this equation, PVR_{MRI} values pre- and post-embolization were 2.8±1.7 WU (P=0.63 for PVR_{MRI} vs. PVR_{RHC}) and 7.8±4.1 WU (p=0.52 for PVR_{MRI} vs. PVR_{RHC}), respectively. The mean difference (bias) between PVR_{MRI} and PVR_{RHC} was 0 with positive and negative levels of agreement of 3.16 and -3.16, respectively.

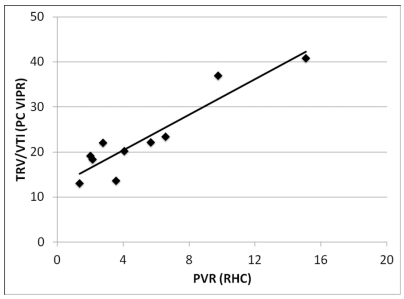

Figure 2. Scatter plot demonstrating relationship between TRV/VTI_{RVOT} from PC VIPR and PVR from RHC. Line represents simple linear regression fit.

DISCUSSION: Several MRI methods of estimating PVR have been evaluated, with a model combining the average PA velocity and RV ejection fraction [4] being one of the more promising. In this study we found that PVR can be accurately estimated noninvasively from the velocity-time integral in the RVOT and the peak velocity of the tricuspid regurgitation just using PC VIPR. Although PVR is an important parameter in the evaluation of patients with PAH, it is also of clinical utility in the management of patients with a variety of other cardiovascular and pulmonary diseases, including congestive heart failure [5], coronary artery disease [6] heart- and liver-transplant [7], and congenital heart disease [8]. Reiter G, et al. recently used 4D flow-sensitive MRI to estimate mPAP by measuring the length of vortices in the proximal main PA [9]. The results from this study indicate that 4D flow-sensitive MRI with PC VIPR can also be used to estimate PVR, complementing the analysis of alterations in flow patterns in the heart and pulmonary arteries.

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