Quantification of Pulmonary Vein Off-Resonance Frequency Through the Cardiac Cycle: Implications for Non-Contrast Pulmonary Vein MRA

P. Hu[1], C. Stoeck[1], D. C. Peters[1], K. V. Kissinger[1], B. Goddu[1], L. Goepfert[1], N. M. Rofsky[1], W. J. Manning[1], and R. Nezafat[1]

[1]Beth Israel Deaconess Medical Center, Boston, MA, United States

Introduction: Non-contrast pulmonary vein (PV) MRA is a potential alternative to contrast enhanced methods for pre-procedural planning and post-procedural evaluation of PV isolation in treatment of atrial fibrillation (AF). Such an approach would be particularly valuable for patients with renal insufficiency at thus at risk for nephrogenic systemic fibrosis. In 2007, 12% of the 150 AF patients referred for evaluation of PV anatomy in our Center were found to have impaired renal function that precluded use of a Gadolinium based PV MRA. A major drawback of non-contrast PV technique compared to contrast-enhanced method is lack of contrast between PV and the surrounding structures that could impact the vessel size measurement and 3D visualization of PV anatomy in clinical electrophysiology guidance system. Because of close proximity of the PVs to the lungs, the PV blood has significant off-resonance due to susceptibility effects. This can be exploited as a source of contrast to selectively image the PVs using steady-state free precession (SSFP) or gradient echo imaging sequences [1, 2]. The stability and variation of this frequency off-set has not been previously studies; therefore, we sought to measure this frequency variation through the cardiac cycle as well as for all four PV branches in a cohort of healthy adult subjects.

Materials and Methods: An imaging sequence was developed to enable measurement of off-resonance frequency throughout the cardiac cycle. Images were acquired using two different echoes with echo difference of ΔTE=2 ms that can resolve frequency shifts up to 500Hz. 6-8 slices were prescribed to image each PV. The imaging parameters were as follows: TR=8ms, TE1=2ms, TE2=4ms, FOV=250 x 250 mm^2, flip angle =20º, free-breathing averaging with 3 averages, spatial resolution of 2 x 2 mm^2. Subsequently, a 3D ECG triggered free-breathing balanced SSFP sequence was used to image PVs with the following parameters: TR=4.5ms, TE=2.2ms, FOV=250 x 250 x 60 mm^3, flip angle =90º, spatial resolution of 1.5 x 1.5 x 4 mm^3 reconstructed to 0.75 x 0.75 x 2 mm^3 . Balanced SSFP has a well-known signal profile modulated by frequency shift [3]. Therefore, by applying a linearly increasing radiofrequency (RF) excitation phase from TR to TR, we shift the frequency response of SSFP signal so that the off-resonant PV blood signal is enhanced while on-resonance signal of blood is suppressed.

All images were transferred to image analysis software (ViewForum 2.0, Philips Healthcare, NL) for further measurement and 3D visualization. The PV off-resonance was measured by defining a region-of-interest in the proximal PV of the generated field maps and calculating its mean off-resonance frequency.

Six healthy adult subjects were imaged using 1.5T Achieva system (Philips) using a 5 element phased array cardiac coil. All studies were approved by our institutional IRB.

Results: Fig. 1 shows an example of off-resonance measurements in the right inferior PV from a healthy adult subject at four phases of the cardiac cycle. Fig. 2 shows the frequency variations for each branch through the cardiac cycle. The right inferior branch has the highest off-set frequency and the mean frequency shifts for all branches stay within a narrow range of 10Hz through the cardiac cycle. Four slices from a 3D SSFP sequence acquired using off-set phase cycling is shown in Fig. 3 that visualize all four branches. Fig. 4 shows a 3D volume rendering view of on- and off-resonance SSFP data sets using the 3D slicer tool (www.slicer.org). With off-resonance SSFP, the enhancement of PV signal and suppression of aorta and inferior vena cava (IVC) make it easier to identify the PV branches in the 3D model.

Conclusion: PV blood exhibits a mean off-resonance of 58~113Hz, with the right inferior PV having the largest frequency shift. We observed minimal RR variation in frequency off-set. By shifting the frequency response of SSFP sequence, we enhance the PV blood signal compared to on-resonance conditions. A combination of both on- and off-resonance SSFP acquisitions is a potential method to obtain coverage for both left atrium and PV.

References: [1] Nezafat et al., ISMRM 2008, p920 [2] Edelman RR, MRM. 2007 57(3):475-84. [3] Scheffler K. MRM 2003 49(4):781-83

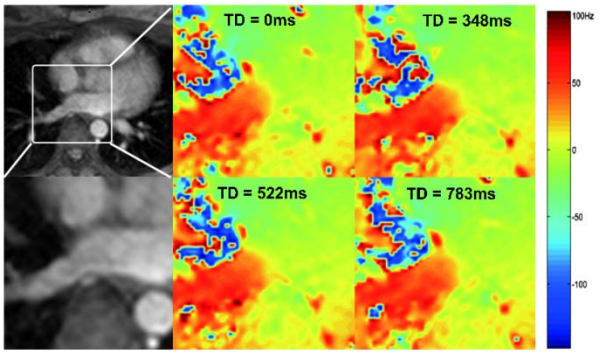

Figure 1: PV off-set frequency map at four cardiac phases (TD=trigger delay).

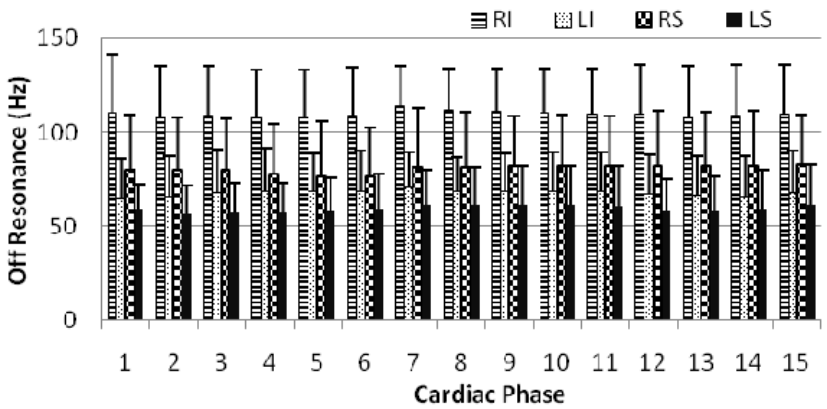

Figure 2: Mean off-resonance frequencies at different branches through the cardiac cycle. RI=right inferior PV. LI=left inferior. RS=right superior. LS=left superior.

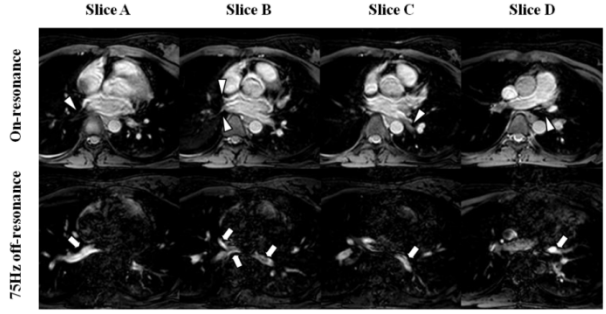

Figure 3: An example of off-resonance SSFP signal enhancement in four PV branches. The on-resonance SSFP images (top row) show the cardiac structures, however the PV ostia are missing. By shifting the SSFP frequency response by 75 Hz (bottom row) using RF phase cycling, the signal from the PV branches is enhanced (arrows).

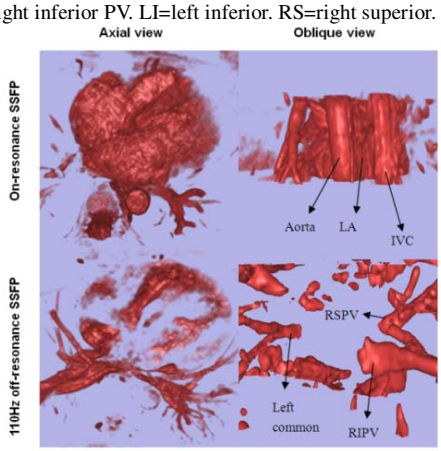

Figure 4: A comparison of 3D volume rendering of on-resonance (top row) and 110Hz off-resonance (bottom row) SSFP PV data sets.