In-vivo distortion of through-plane flow by small off-resonance error in spiral phase-contrast imaging

Iain T Pierce[1,2], Peter D Gatehouse[1,2], and David N Firmin[1,2]
[1]NHLI, Imperial College London, London, United Kingdom, [2]CMR Unit, Royal Brompton Hospital, London, United Kingdom

Summary: To explain a previously unrecognised spiral imaging artefact arising from the interaction of flow-related phase-shifts and off-resonance effects over the vessel cross-sectional area.

Introduction: The effects of off-resonance frequency errors during spiral readouts are known (1), as is the robustness of spiral imaging of flow (2). Here we explain previously unrecognised intra-voxel dephasing consequences of two sources of phase curvature over the vessel cross-section in through-plane flow spiral imaging *i.e.* off-resonance and the velocity-encoded phase-shift, including the impact on *in-vivo* measurements.

Methods: To investigate the interaction between velocity-encoded phase shifts and the off-resonance phase curvature, we acquired laminar through-plane flow phantom (50cm/s) and popliteal artery studies (Venc=50cm/s) with off-resonance offsets ± 0 10, 20, 40Hz representing <1ppm at 1.5T. Reference and velocity-encoded magnitude and phase images were obtained (as a cine *in-vivo*). Spiral FOV was 150 mm, 1mm resolution, duration 25.7ms; TE/TR 4.0/32.7 ms, FA 30°, 4 interleaves.

Results: Figure 1 shows magnitude and phase of the Reference and Velocity-encoded images, with corresponding velocity maps, at the same cardiac phase with a range of off-resonance frequencies. High velocities cause distortion of the vessel cross-sectional profile in the velocity-encoded image, depending on the combination of off-resonance and flow-related phase shifts. From the velocity maps, peak velocity was measured at 37.8, 48.6, 56.3cm/s at -40Hz/0/40Hz off-resonance. The *in-vivo* and phantom images demonstrated opposing contraction and dilation artefacts of the vessel depending on the combination or cancellation of the off-resonance and flow-related phase shifts. The artefact changed (as if from + to – off-resonance frequency) when the flow direction (exclusive-)or velocity-encoding polarity were reversed, and did not occur in velocity-compensated reference images.

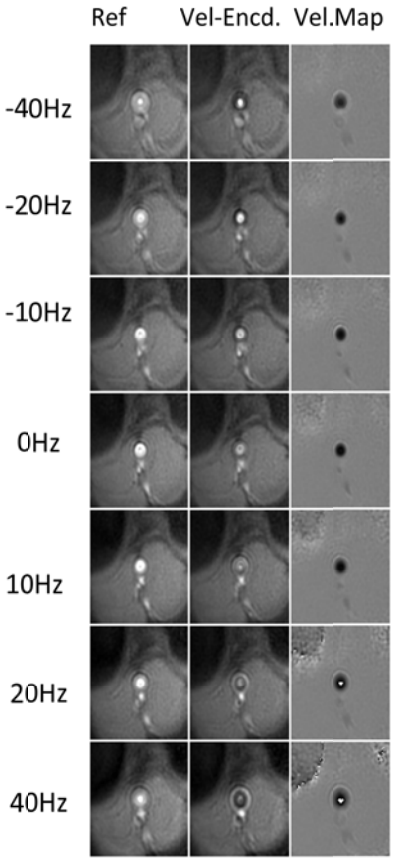

Figure 1: Images with corresponding velocity maps of popliteal artery at peak velocity at 50cm/s VENC with off-resonance offsets -40...0…40 Hz. The velocity-encoded magnitude images are distorted by the radial redistribution of signal loss due to shear phase dispersion. This occurs because of the interaction of off-resonance and flow-related phase curvatures across the vessel which add or subtract depending on the combination of flow-direction, Venc polarity and off-resonance frequency polarity.

Discussion: As basic explanation, Figure 2a) depicts the ideal diametrical phase line profile across a tube with no flow-related phase shifts (red line = on-resonance and blue/green lines = phase curvature induced by +/-40Hz off-resonance. In Figure 2b), the red line shows velocity-encoded phase across a vessel with parabolic flow. The blue line shows the consequence of adding an off-resonance phase-curvature: the increased radial slope worsens intra-voxel dephasing in all but the central pixels of a laminar flow ("contraction" artifact). The green line shows where opposing phase curvatures lead to a levelling of the radial phase slope at some radius, which can lie *outside the true lumen* ("dilation" artifact). The distorted velocity distribution over the vessel, in itself potentially problematic, also distorts peak velocity by ~20% at 40Hz off-resonance in this setup. Separate tests eliminated through-plane gradient fields as a cause, including eddy-current effects after the velocity-encoding pulses. Off-resonant frequencies up to around 20Hz are not immediately obvious if the on-resonant image is not available for comparison, so this artifactual vessel dilation and contraction effect might easily occur without much warning available from the general image quality. This effect can be corrected by demodulation of rawdata provided that the entire vessel cross-section is at one frequency.

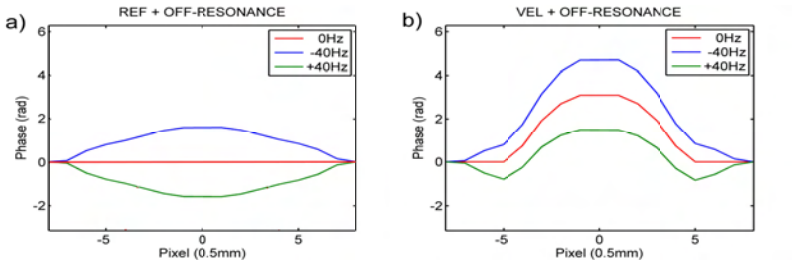

Figure 2: Please see Discussion.

Conclusion: The effects on flow imaging and velocity distributions at <1ppm off-resonance are possibly difficult for >20ms spiral readouts in small vessel applications, perhaps worse near main field inhomogeneities such as lungs. Shorter spirals and avoiding large intra-voxel radial phase shear would reduce this sensitivity but it may still occur in high-field rapid flow work.

(1) Yudilevich , Stark 1987. (2) Meyer, Hu et al 1992.