CNR Optimization in Variable Pitch PROPELLER MRA

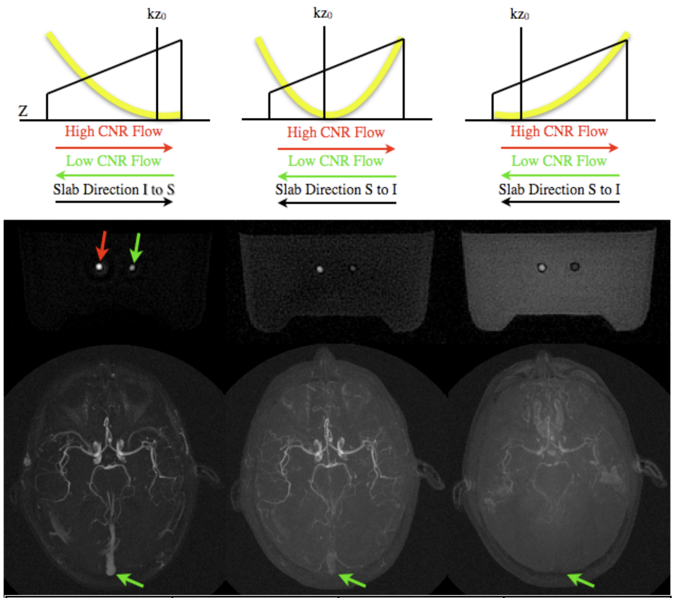
N. R. Zwart[1], and J. G. Pipe[1]
[1]Keller Center for Imaging Innovation, Barrow Neurological Institute, Phoenix, Arizona, United States

Introduction: Variable Pitch PROPELLER MRA is a 2D-3D hybrid sequence that employs frequency swept 'chirp' rf pulses to acquire thick-overlapping-slabs as a 2D acquisition (ie. there are no phase encodes for the slice direction). The parabolic phase induced by the chirp rf pulse can be reconstructed to obtain prescribed slice thickness with similar SNR benefits to a 3D sequence[1,2]. The in-plane trajectory is a PROPELLER-GRE with asymmetrically sampled blades for a short TE. The blades are rotated 360˚ which provides critically supported high frequency k-space and a highly oversampled center of k-space for PROPELLER motion correction[3] in MRA. Blood contrast is attained through inflow enhancement and is further augmented by partially refocusing G_z[4], which has the effect of shifting the MTF and localizing the center of k_z-space in the Z domain across the quadratically encoded slab[5]. This work focuses on the optimization of arterial CNR.

Procedure: A 2^8 factorial experiment was run on a flow phantom that consists of two tubes carrying flow in opposite directions, bathed in tap water. The 8 tested parameters are the (1) number of lines per blade, (2) flip angle, frequency sweep ((3) magnitude and (4) direction), (5) shift of MTF (in Z-kz), TONE ((6) magnitude and (7) direction), and (8) the slab acquisition direction. 128 scans were acquired with the flow (10cm/s) normal to the slice plane. The effects of slab acquisition direction were inferred by counting the flow in the opposite direction as an additional treatment making the experiment a full 256 runs.

The series of images were segmented by hand using the same mask for each image. CNR of each flow was calculated against the stationary tap water signal. Linear regression analysis was used to characterize the sequence CNR and maximize an 'Image Quality' metric (eqn. 1). SAR was constraint by a maximum value defined in terms of chirp frequency, flip angle and peak TONE.

$$IQ = CNR_{arterial} - CNR_{venous} \quad (1)$$



Lines Per Blade	40	40	20
Shifted MTF	70% (left)	30% (right)	70% (right)
TONE (slope sign)	+	-	-
Slab Direction	I to S	S to I	S to I

Figure 1: Phantom and in vivo images from highest arterial CNR (left) to lowest (right). Phantom images (2nd row) show flow enhancement and suppression in two cross-sections of opposing flow. The prescribed MTF (top row) superimposed across slab thickness in the slice direction shows the time course of collected spatial frequencies given slab acquisition direction and flow direction. The parabolic phase induced by the chirp pulse is superimposed on the MTF; the vertex marks the center of kz-space. (bottom) In vivo images show high contrast at the expense of venous contamination (left), a mixture of both (middle), and full venous attenuation with lowest arterial contrast. Table shows 4 parameters out of 8 that where changed to achieve each contrast. Other parameters where held constant in accordance with model predictions as follows: flip angle 16˚, TR 5.5ms, chirp sweep covers 16 slices per blade slab. No venous sat pulse was used in any scans.

Discussion: The linear regression produced a coefficient of determination (R^2) of 0.996. The maximum CNR, for the flow direction corresponding to arterial, from the phantom series was 133 (Fig 1:2nd row: left), while an alternative method (Fig 1:2nd row:right) had a CNR of 24 (intermediate CNR is 31). The maximal CNR of the former method comes at the expense of not fully attenuating venous flow. Addressing venous flow through shifting the MTF to the leading slab edge adds unattenuated signal from stationary spins. Intuitively the MTF on the right will yield the desired image quality for the following reasons: (1) Arterial inflow will pass through the center of k-space first, collecting high signal content, then high spatial frequencies are collected as flow passes deeper into the slab, becoming more attenuated. (2) Venous flow gets the opposing effect. (3) Further attenuation is imparted to flow in the same direction as the slab direction. (4) High signal content of stationary spins is also collected before they are fully saturated, lowering the CNR of both arterial and venous flow. The middle and right images where chosen by linear regression analysis by weighting the CNR_{venous} term more heavily. This suggests that a separate venous attenuation mechanism will have to be adopted, such as a venous saturation pulse.

References: [1] Pipe, J. MRM 36:137; [2] Pipe, J. MRM 33:24; [3] Pipe, J. MRM 42:963; [4] Pipe, J. MRM 41:309; [5] Pipe, J. MRM 39:625