Introduction: Signal to noise ratio gains in low VENC phase contrast MRI are limited by the ability to successfully unalias phase measurements that fall outside the -π to π interval. The ability to unalias phase measurements on a per pixel basis is limited by errors in the measurements due to noise and signal biased phase [1]. The method presented in this work provides more time efficient gains in SNR compared to a well known '3-point' (Fig. 1a) method presented by Lee et al [2]. This work extends previously presented theory in unaliasing sensitivity [3] to measured time efficiency in phantom experiments and practical viability in-vivo.

Methods: The proposed method measures multiple velocity sensitive directions at low VENC. Measurement directions are distributed as uniformly as possible using charge repulsion [4] or the vertices of a regular polyhedron (Fig 1b). The sign of each VENC is then adjusted to maximize gradient moment balancing. *Time efficiency:* Phantom experiments at a VENC of 50, 25 and 15 cm/s were performed using a laminar flow setup in a glycerine bath, with a peak flow velocity of 35cm/s. The velocity noise (σ_v) was measured in the surrounding bath (assuming equal spatial noise distribution). *In-vivo:* A fully sampled stack of spirals scan (parameters: TE/TR: 5.1/18ms, ADC: 7ms, FOVxy/z: 24cm/7cm, Res.: 1mm^3, scan time: 3.8min, 3-point VENC: 80/40 cm/s, 6-dir VENC: 40 cm/s) was used to acquire a 3-point and proposed 6-direction neuro-MRA. All scans were performed on a GE 3T Signa Excite system. Unwrap errors were corrected using signal based weighted replacement [1].

Results: *Time efficiency:* The average noise (normalized by VENC across each experiment) relative to a 3-direction low VENC acquisition is shown in table 1. The max VNR efficiency, calculated relative to scan time, is 1.7 times greater than the 3-point method using the 6-direction configuration. With the exception of 7-directions, additional measurements appear to improve the unaliasing efficacy in areas of phase bias (i.e. VENC of 15cm/s), while these experiments show the 3-point method to be the most robust to bias. *In-vivo:* Fig. 2 shows reconstructed MIPs of each method. Both methods show a robustness to phase bias and noise in phase unaliasing efficacy. The proposed method shows increased vessel conspicuity by comparison.

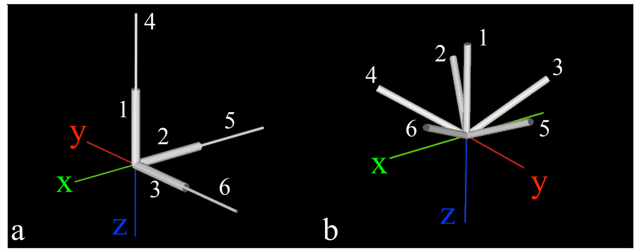

Fig. 1: The relative VENC and directions used in the 3-point (a) and proposed 6-direction (b) methods. (a) uses high VENC data to unwrap low VENC sets. (b) uses mutual information in all low VENC sets to unwrap aliased phase.

Table 1: The relative VNR time efficiency of the proposed method (6-9 directions) compared to the 3-point method using the same low VENC.

Method	Relative Noise*(σ_v)	Relative Time	Relative VNR Efficiency
3-point	1	7	1
6-dir	0.587	7	1.702
7-dir	0.529	8	1.651
8-dir	0.496	9	1.567
9-dir	0.475	10	1.473

*properly unaliased

Conclusion: The proposed method provides a means for obtaining an increase in VNR (by about 1.7) over the 3-point method, for the same scan duration. In practice, phase aliasing is effectively reconstructed by both methods in-vivo.

References: [1] Pipe, MRM, 49, 2003; [2] Lee, MRM, 33, 1995; [4] Zwart, ISMRM, abs #2795, 2011; [3] Hasan, JMRI, 13, 2001

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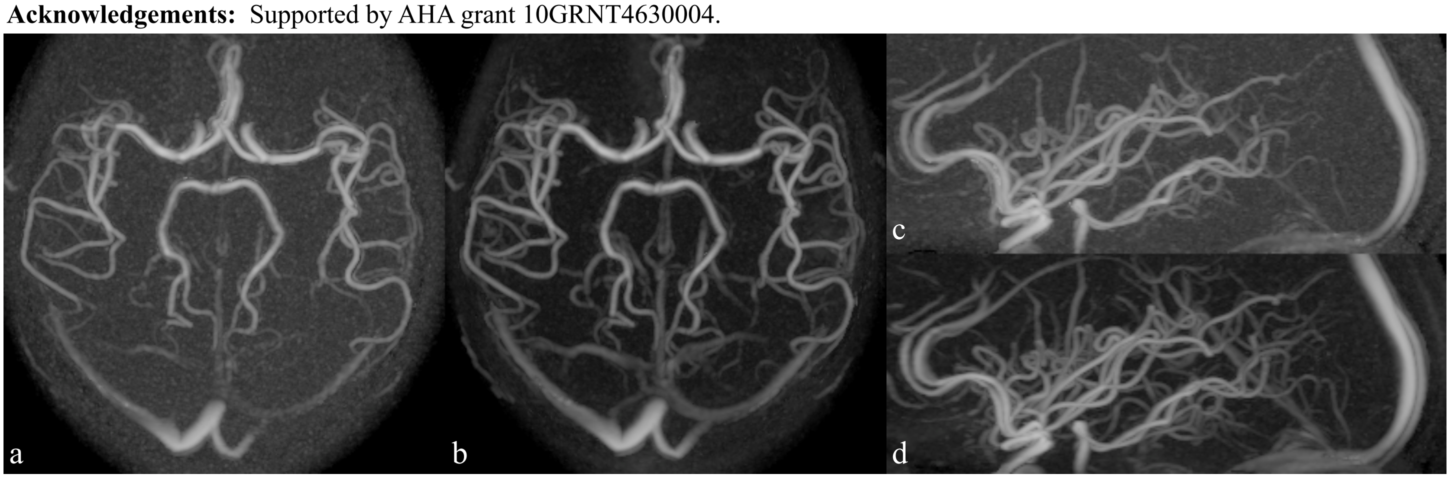

Fig. 2: In-vivo axial MIPs using the 3-point (a) and 6-direction (b) methods. Sagittal MIPs are shown in (c) and (d) respectively. Each image is gamma corrected with γ=0.1 and multiplied by the signal magnitude. The scan time for each method was 3.8min.