Evaluation of n^th Order Polynomial Phase Correction in Reprojected Line Scan Phase Contrast MRA

E. J. Offerman[1], I. Koktzoglou[1,2], C. Glielmi[3], and R. R. Edelman[1,4]

[1]Radiology, Northshore University HealthSystem, Evanston, IL, United States, [2]Radiology, The University of Chicago, Chicago, IL, United States, [3]Siemens Healthcare, Chicago, IL, United States, [4]Radiology, Northwestern University, Chicago, IL, United States

Introduction: Reprojected Line Scan Phase Contrast (rLSPC) MRA is a rapid line scan phase contrast method that produces a coronal cine of blood flow and can provide information on the hemodynamic significance of a stenosis [1]. It is acquired in line by line projections in real-time over the cardiac cycle. Although the method can rapidly demonstrate flow velocity over large vascular territories, it suffers from spatially varying phase shifts due to eddy currents and pre-steady-state instabilities. Phase correction (PC) is needed to improve image quality and consistency of the velocity quantification. Presented is a PC method that employs a polynomial curve fitting technique. The merit of the method is assessed and orders of fit are compared.

Methods: rLSPC was performed with a 1.5T MR scanner (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany) in five healthy subjects and one patient with partial occlusion in the right iliac artery. The sequence consisted of a spoiled gradient echo readout with the following parameters: 9 stations; 60 3-mm-thick slices per station; flip angle 90°; TR=20ms; TE=4.3ms; bandwidth=625 Hz/pixel; VENC=20-150(cm/s). The polynomial fitting technique is a derivation of the 2D polynomial PC method employed by Lankhaar et al. in [2]. An n^{th} order 1D polynomial was fit to pixels of stationary background phase and then subtracted from the same line in the final cine. This was performed for each line in each frame of the cine. PC of different polynomial orders (n = 1 to 8) were compared to themselves and to uncorrected rLSPC using two criteria: (a) flow velocity measurements at four locations within the vessel lumen; and (b) amplitude of background phase fluctuations which was quantitated as the time-series standard deviation of the background phase.

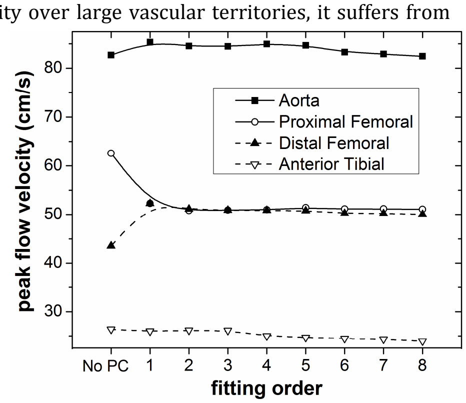

Figure 1. Peak flow velocity vs. fitting order of PC. Each point is the average of five healthy subjects and one patient.

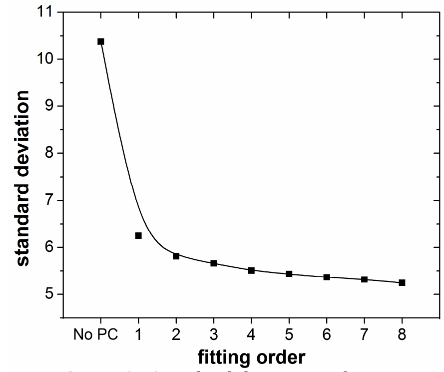

Figure 2. Standard deviation of background (non-vessel) phase vs. fitting order of PC. Each point is the average of five healthy subjects and one patient.

Results: Flow velocity in the aorta and anterior tibial artery was not substantially altered by any fitting order (**Fig. 1**), however measurements at proximal and distal femoral locations showed convergence to a common velocity, suggesting that correction of intra-station phase gradients (see **Fig. 3**) may improve velocity quantification. Higher fitting orders did not significantly alter proximal and distal femoral velocities. The standard deviation of background phase was reduced 40% with 1st order PC (**Fig. 2**), which manifested as improved image quality with the reduced background phase variation over time. High order PC (> 3rd order) demonstrated little additional improvement. **Figure 3** displays the obvious improvement in image quality of uncorrected rLSPC (top) with 3rd order PC (bottom). Inter-station and intra-station phase shifts were nearly completely eliminated with polynomial PC.

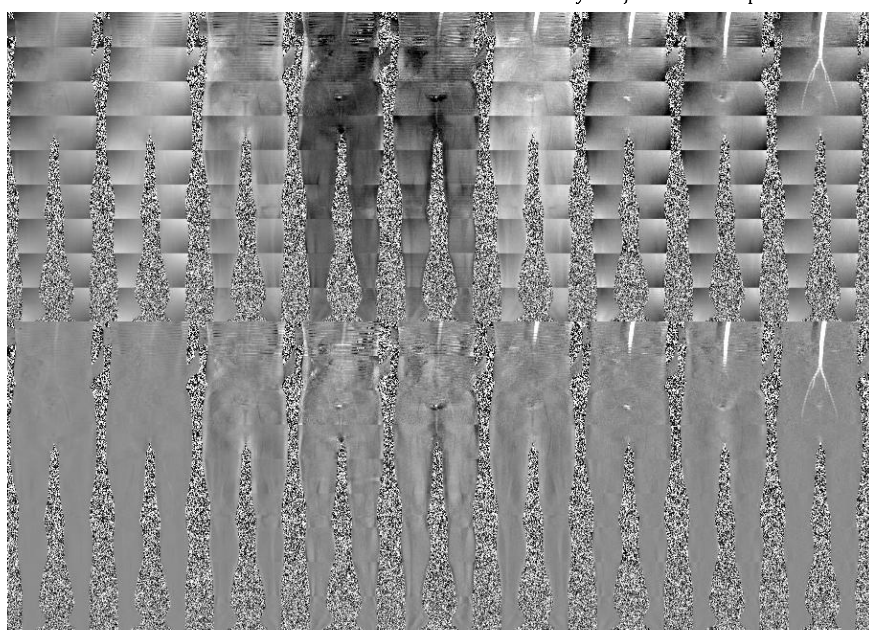

Figure 3. Montage of the first nine frames of the cine without PC (top) and with 3rd order polynomial PC (bottom) in a healthy subject. Temporal resolution is 20ms. With polynomial PC, the substantial phase fluctuations in frames 3-6 of uncorrected rLSPC are reduced and intra-station phase gradients are eliminated.

Discussion and Conclusion: One-dimensional polynomial PC of rLSPC provides vast improvement over uncorrected rLSPC by eliminating background phase shifts in stationary tissue which can alter the velocity values and reduce image quality. However, this method has several drawbacks. First, in order to achieve optimal fit, the intra-vessel velocities must be segmented from background velocities, which is done using an empirically determined velocity threshold (values > 40 cm/s are ignored in the fit). Velocities in smaller vessels may not be removed, which can reduce the accuracy of the fit. Secondly, the PC process can be computationally intensive and time consuming when high order fitting is used. For instance, 8th order PC took 83% longer than 2nd order PC to perform. Considering this and the marginal improvement seen at high fitting orders, it may be prudent to use low fitting orders (< 3rd order).

References: [1] Edelman et al. MRA Club 2010. [2] Lankhaar et al. JMRI 2005;22:73-79.