# Variable velocity encoding of 4D phase-contrast sequences to improve blood flow visualizations

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## Introduction

Time-resolved, three-dimensional, three-directional phase contrast sequences (here denoted 4D-PC) are important tools for understanding blood flow hemodynamics [1-3]. In order to depict detailed and complex flow patterns, high spatial and temporal resolution is needed. However, smaller voxel sizes introduce higher levels of noise which may distort blood flow visualizations and their interpretation. An approach to reduce noise is to adapt the velocity encoding sensitivity (Venc) to the expected velocities in each timeframe for the specific area of interest. By contrast, conventional phase contrast sequences determine the velocity encoding from the maximal velocity in the complete cardiac cycle. To our knowledge, phase-contrast sequences with variable Venc have only been used with velocity encoding in one single dimension [4]. The purpose with this work is to demonstrate potential benefits of a novel 4D-PC sequence with variable velocity encoding in all three spatial directions.

## Materials and methods

A 4D-PC sequence was modified to allow individual velocity encoding for each dynamic heart phase and spatial directions. All measurements were performed on a 3T Philips Achieva MR system (Philips Healthcare, the Netherlands). The 4D-PC sequence consisted of a segmented, prospectively triggered 4D turbo field echo (TFE) sequence, with TE/TR=4.0/7.8 ms. A static phantom was used to quantify the noise as a function of Venc. Velocity noise was calculated in Matlab v. 7.9.0 (The MathWorks Inc., USA) by placing 12 equally sized volumes-of-interest (VOIs, 5×5×4 pixels) in the static cylinders for each dynamic heart phase. A noise estimate was obtained in both the magnitude and phase images by applying the equation

$$\sigma = \sqrt{\frac{\sum_n \sum_m \left(v_{n,m} - \overline{v_n}\right)^2}{n \cdot m - n}} \qquad (1)$$

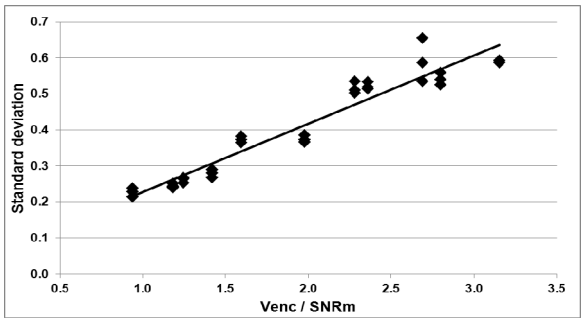


*Figure 1. Measured standard deviation in phase images (static phantom part, all three velocity directions included), and corresponding Venc / magnitude SNR ratio*

In which *n* is the VOI number and *m* the number of voxels in each VOI. Additionally, a healthy volunteer was scanned using two 4D-PC sequences; one with constant Venc = 170 cm/s, and one with Venc optimized for the blood flow dynamics in the ascending aorta, respectively. The 4D-PC datasets were exported to the GTFlow software v.1.4.13 (Gyrotools LLC, Switzerland), for visualization.

## Results

In the proposed variable Venc sequence, noise was seen to change linearly with Venc (Figure 1), as expected from theory. Blood flow visualizations performed in a healthy volunteer resulted in visually different images of the flow patterns (Figure 3,4). The reduced noise of the variable-Venc sequence translated into smoother, more physiologically sound, flow maps than was the case for the constant-Venc case.

## Conclusions

The noise measurements in the phase contrast images confirm the noise dependence on Venc and SNR in the magnitude images [5]. Without sacrificing scan time, substantial improvement of the depiction of blood flow patterns in the late cardiac cycle can be achieved by optimizing the velocity encoding throughout the cardiac cycle.

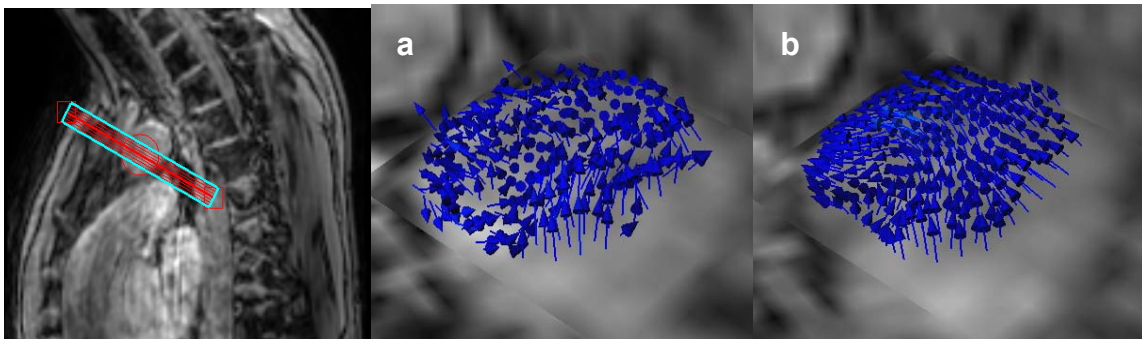


*Figure 2. Position of the visualization plane in the ascending aorta. Figure 3-4. Comparison of flow patterns acquired 603 ms after the RR-peak with a) a constant-Venc sequence, and b) a variable-Venc sequence. Note the increased homogeneity of the velocity vectors in fig.4, indicating less influence of noise in the variable Venc sequence.*

## References

[1] Kilner, P.J., et al., Nature, 2000 [2] Wigstrom, L., et al. Magn Reson Med, 1999 [3] Markl, M., et al. J Magn Reson Imaging, 2003 [4] Ringgaard, S., et al, Radiology, 2004 [5] Pelc, N.J., et al. J Magn Reson Imaging, 1991.