# A Fast Reduced TE 4D Spiral PC MRI Sequence for Assessment of Flow and Hemodynamics

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## Introduction

4-D flow MRI has been widely investigated to quantify arterial hemodynamics and to visualize the temporal motion of fluid particles in detail [1]. In addition to comprehensive anatomical and flow information in both in-plane and through-plane directions, 4D flow imaging results in shorter total scan time compared to 3-D flow imaging or multiple 2D-slice imaging which require covering a volume with three separate scans and three flow directions. However, conventional 4D PC-MRI based on the Cartesian trajectory results in a very long scan. Spiral trajectory results in shorter readout echo time (TE) and reduces the scan time [2]. Herein, a 4D spiral PC MRI technique was designed to reduce the scan time compared to conventional technique. 4D spiral PC MRI has the added advantage of reducing the phase error and signal loss due to long TE.

## Methods

In Cartesian PC MRI sequences, slice excitation, rephasing, and velocity encoding gradients need to be applied during TE. These gradients prolong TE and may lead to phase errors and velocity miscalculation. However, the spiral trajectory benefits from shorter TE due to removal of the phase encoding gradient and the rephasing part of the readout gradient. Figure 1 demonstrates a 4D PC MRI sequence that was designed using a 3D stack of spirals trajectory. In order to further shorten the TE, the flow encoding/compensated gradient was combined with refocusing part of slice select gradient. Three consecutive flow encoding scans each of which included the flow encoding gradient in one of the three geometrical directions followed by one reference scan were applied to provide flow information in three directions. Imaging was performed on a Philips Achieva 1.5T scanner (Philips Healthcare, Best, NL) using a combined 16-element SENSE Neurovascular coil capable of imaging carotid vessels from aortic arch to circle of willis. Five normal volunteers with a mean age of 27±4 years were scanned using standard 4D cine Cartesian PC MRI sequences as well as the proposed 4D cine spiral PC MRI sequence. Flow assessment was performed in the carotid arteries in an axial 3D volume with 10 slices and a 3D slab thickness of 5 mm for each slice. The volume was located 15 mm (including 3 slices) proximal and 35 cm (including 5 slices) distal to the carotid bifurcation. Phase errors due to eddy current and hardware imperfections were corrected using a static phantom which was scanned with identical parameters prior to the main scan. The phase error in static phantom MR image was assumed to be only due to eddy current and hardware imperfection and was subtracted from the in-vivo scan.

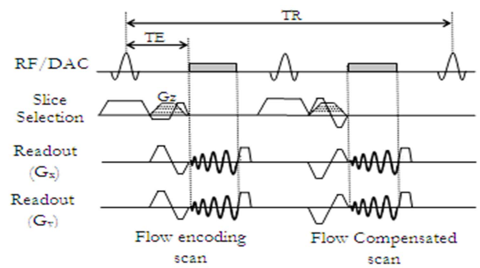



Figure 1: Schematic of 4D spiral PC MRI

The scan parameters for two sequences were TE/TR = 4.4/7.7 ms (for Cartesian trajectory), TE/TR = 2.1/9.3 ms (for spiral trajectory), FOV= 160*160*50 mm, Venc= 150 in all three flow directions, flip angle= 10, spatial resolution= 1.5*1.5*5.0 mm, and 12 cine frames in each cardiac cycle. For spiral trajectory various number of spiral interleaves (20,30,50,60) and readout duration (2,3,5,10, msec) were examined and number of interleaves of 30 and readout duration of 5 msec was shown to be a good compromise between flow measurement fidelity and scan time. The scan time for the conventional sequence was 6:16 minutes and for the proposed 3D technique was reduced to 3:31 minutes.

## Results

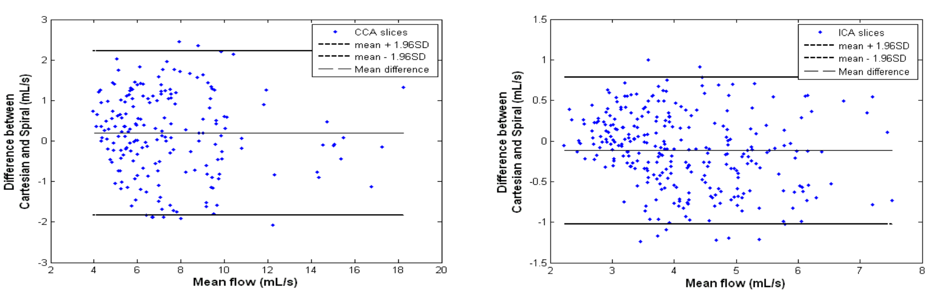
Flow assessment was carried out in right CCA for three slices located proximal to bifurcation as well as five slices distal to bifurcation in the ICA in 4 volunteers. Figure 2 demonstrates the Bland-Altman plot representing the mean difference of flow measured using conventional 4D PC MRI and 4D spiral PC MRI. Mean flow in each slice and in each cardiac phase in 4 volunteers generated 144 data points in CCA and 288 data points in ICA. The Bland-Altman plot reveals a reasonable accuracy for 4D spiral PC MRI. Figure 3 shows blood flow pathlines for one of the volunteers in the systolic cardiac phase of the cardiac cycle in the right carotid artery with both techniques. There is good correspondence between flow pathlines of the 4D spiral PC MRI and conventional technique. 4D spiral PC MRI shows slight erroneous flow pathlines in ICA possibly due to off-resonance artifact.

## Conclusion

A 4D spiral PC MRI was implemented with the goal of reducing the scan time compared to conventional 4D PC MRI without scarifying accuracy of flow assessment. We note that in the proposed sequence TE was significantly reduced compared to Cartesian trajectory which will lead to reduction of the signal loss in the case of disturbed and turbulent flows in the presence of atherosclerotic disease.

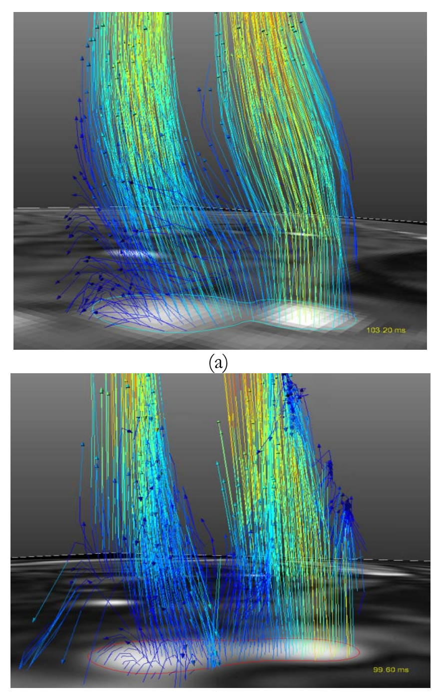
## References

[1] Markl M, et. al., J Magn Reson Imaging, vol. 25, pp. 824-31(2007).
[2] Nayak K. S., et. Al., Magn Res in Med, vol. 50, pp. 366-372, 2003.




(a) (b)

Figure 2: Bland-Altman analysis comparing flow from 4D spiral PC with 4D conventional PC in CCA (left) and ICA (right) in four normal volunteers, Each point represents flow rate for a specific time during the cardiac cycle.



(a)

(b)

Figure 3: Flow pathlines during a systolic phase of the cardiac cycle in the right carotid artery (magnified at carotid bifurcation) acquired using (a) conventional 4D Cartesian PC MRI and (b) 4D spiral PC MRI.