The Effect of Phase Cross-contamination by Partial Central K-space in Cine Phase Contrast MRI

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Introduction: The variation of blood flow in artery is generated by systole and diastole during one cardiac cycle. Using velocity-sensitive PCMRI with retrospectively gated techniques, we can observe the velocity profile in one heartbeat. PCMRI has been widely used in blood flow and cerebrospinal fluid production rate [1, 2]. To accurately measure the velocity profile in one heartbeat, the cine PCMRI with high temporal resolution is needed for more sampling cardiac phases. Because the diameter is small in most vessels, the cine PCMRI with high spatial resolution is also needed. The long scan time in cine PCMRI is due to high temporal and high spatial resolution. Recently, the data share of K space techniques are highly decreased the acquisition time and widely applied on clinical examination. It is also to apply on flow measurement in PCMRI [3].Using keyhole technique, segmented central k-space line only, can accelerate scan time but also make blurred image in phase encoding direction. The blurred image can be reconstructed using phase correction methods such as Homodyne [4] and POCS [5]. The keyhole technique is suitable for dynamic scan with adding one high spatial resolution in static scan for phase correction. Cine PCMRI is a dynamic phase image on same slice and consequently can be accelerated by keyhole technique. Although the blurred image can be modified and looks like a high resolution image, the retrieved intensity value in phase image may be different with original value. Furthermore because the point spread function (PSF) is only spread along phase encoding direction, the interspace of two vessels should be an important factor for cross-contamination of two vessels in phase image. In this study, simulations on the six circles with different interspace were used to analyze the phase error based on the different number of central k-space line and cyclic flow patterns. Moreover, reducing the number of central k-space line from a real cine PCMRI with high temporal and spatial resolution was used to simulate the phase cross-contamination by keyhole scan.

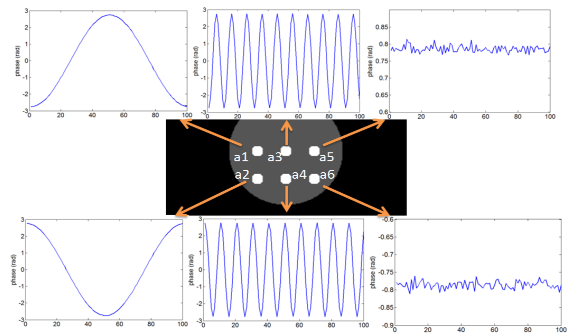

Fig 1. The 100 magnitude and phase images (256x256) were created as numerical phantom simulation. The phase oscillation was 1 Hz, 10 Hz and DC in a1, a3 and a5, respectively. The reverse phase oscillation corresponding to a1, a3 and a5 was in a2, a4 and a6.

Method: numerical phantom simulation: Fig.1 illustrates six small circles (a1~a6) with 10 pixels in diameter inside a large circle background (120 pixels in diameter) which were used to simulate blood vessel on 256 x 256 magnitude image, and the different sinusoidal wave with 100 time points were used to simulate flow pattern of one cardiac cycle on 256 x 256 phase image. The phase oscillation with 1 Hz, 10 Hz and DC was in the region of a1 (amplitude : $-7\pi/8\sim7\pi/8$), a3 (amplitude : $-7\pi/8\sim7\pi/8$) and a5 (amplitude : $\pi/4$), respectively. The reverse phase oscillation corresponding to a1, a3 and a5 was in a2, a4 and a6. Three interfaces between two rows with triple, double and single length of diameter were used to simulate for cross-contamination of two vessels (Fig. 2). Gaussian noise (SNR=30) was added in all 100 magnitude and phase images. The numbers of segmented central k-space line were 256 192, 128, 64, 32, and 16 for simulating the phase change in different partial k-space. The magnitude image (256x256) at first time point was used for phase correction using POCS reconstruction. This whole process was repeated 1000 times. Mean errors of the 1000 simulations for each max phase errors in 100 time points were calculated and compared with original phase without noise. **PCMR image simulation:** Cine 2DPC MR measurements in neck were performed using optimal scan parameters (TR/TE= 9.85/2.78 ms; flip angel=10°; matrix size 192×192; FOV 200x200; venc=120 cm/sec; slice thickness=10mm). 80 cardiac phases were acquired and rearranged with retrospective electrocardiographic gating in a cardiac cycle. The numbers of segmented central k-space line were 192, 128, 64, 32, 16 and 8 for simulating the phase change in different partial k-space. The magnitude image (192x192) at first time point was used for phase correction using POCS reconstruction. The two ROIs in carotid vein were circled to evaluate the phase error and cross-contamination by carotid artery. In this study, the max phase errors were calculated from the maximum difference in phase curve in one cardiac cycle between full k-space and partial k-space.

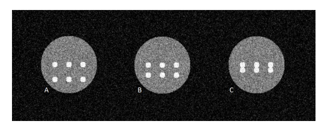

Fig 2. Three interspaces between two rows with (A) triple , (B) double and (C) single length of diameter.

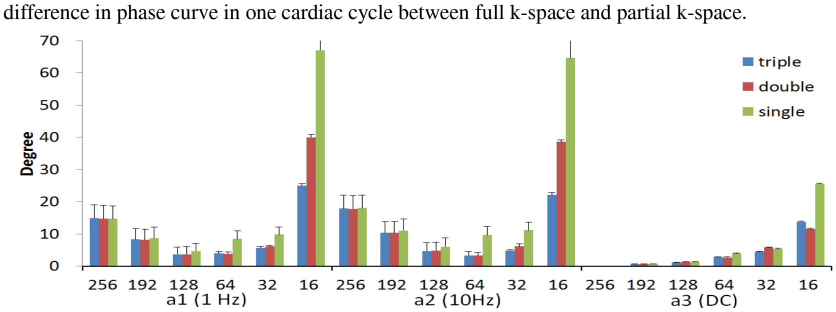

Fig 3. The diagram shows the results in numerical phantom simulation. Because the Gaussian noise is distributed on phase image to mimic the condition in acquirement, the max phase error comparing with original phase is larger in full k-space which enrolls more noise power in high frequency. The phase cross-contamination is the highest at two regions side-by-side in phase encoding direction.

Results: Fig. 3 plots the phase error in a1, a3 and a5 along with interspaces and numbers of segmented central k-space line. Because the phase errors in a2, a4 and a6 are similar with a1, a3 and a5, Fig. 3 plots the results in a1, a3 and a5 only. Fig. 4 shows the two ROIs (R1, R2) in carotid vein and their phase curve in one cardiac cycle. The R1 is in this area which below carotid artery in phase encoding direction, and R2 is out of this area. The max phase errors in R1 are 0.41, 0.98, 3.35, 15.96 and 19.67 degree with 128, 64, 32, 16 and 8 central k-space lines, respectively. And the max phase errors in R2 are 0.27, 0.67, 2.90, 8.26 and 12.94 degree.

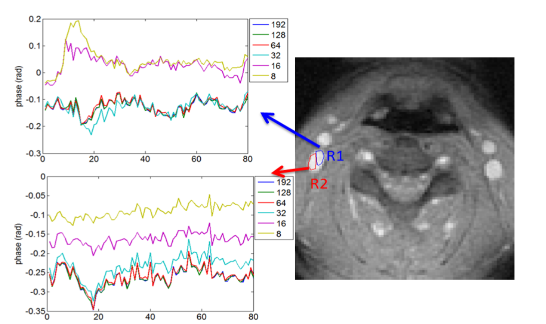

Fig 4. The figure shows the results in PCMRI simulation. R1 is in the upper area of vein and near artery. It is obvious that phase cross-contamination by carotid artery in smaller k-space line.

Discussion: Because the Gaussian noise is distributed on phase image and the noise power is high frequency weighting on k-space, the max phase errors comparing with original phase are larger for higher full k-space (256 and 192) than partial k-space (128 and 64). The phase cross-contamination is increased as smaller numbers of k-space lines and shorter interspace in phase encoding direction. In conclusion, both numerical phantom simulation and PCMR image simulation results indicate that the acceptable phase image should be reconstructed from partial central k-space with same or larger 32 lines of central k-space.

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