Towards real-time 3D phase-contrast flow MRI

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Target Audience: Cardiovascular magnetic resonance methodology, MR flow and motion quantitation.

Purpose: Phase Contrast MRI is an established technique in the field of quantitative flow imaging. 2D phase contrast MRI is the commonly used method to image through-plane flow. Previous studies mainly focused on extending the ECG gated Cine 2D phase contrast MRI to other flow directions for imaging 3D flow [1]. Real-time phase contrast MRI using undersampled radial FLASH and nonlinear inversion reconstruction has been developed recently to image through-plane flow [2]. The aim of this study is to realize real-time 3D flow imaging along with undersampled radial FLASH and nonlinear inversion reconstruction.

Materials and Methods: All experiments were performed on a 3T MRI system (TIM Trio, Siemens Healthcare, Erlangen, Germany). *Invitro* and *Invivo* studies were performed with 32 channel head coil and cardiac coil (16 anterior and posterior element arrays) respectively. A flow phantom designed to image flow in multiple directions was used for *invitro* experiments. The flow phantom consists of large (20 mm diameter) and small tubes (10 mm diameter) to imitate the flow conditions present in the large and smaller blood vessels of the human body. *Invivo* cardiac studies were performed on normal healthy volunteers (n=6) of heterogeneous age group. Written consent was obtained from all subjects before the measurements. A highly undersampled radial FLASH phase contrast sequence and regularized nonlinear inversion reconstruction were used to obtain phase contrast maps. The phase contrast sequence was velocity encoded in three directions with respect to the image orientation (read(x), read(y) and slice) to image in-plane and through-plane flow as shown in figure 1. The first interval without any velocity encoding served as reference for the phase difference calculation. A total of four images for each measurement were calculated consisting of one magnitude image and one phase contrast map for every encoded flow direction. The scan parameters for the experiments were VENC 150 cms^{-1}, TR/TE/α 4.19ms/3.39ms/10°, in-plane resolution 2 mm, slice thickness 6 mm, FOV 256 mm, 4 × 7 spokes resulting in a measuring time of 112 ms per dataset.

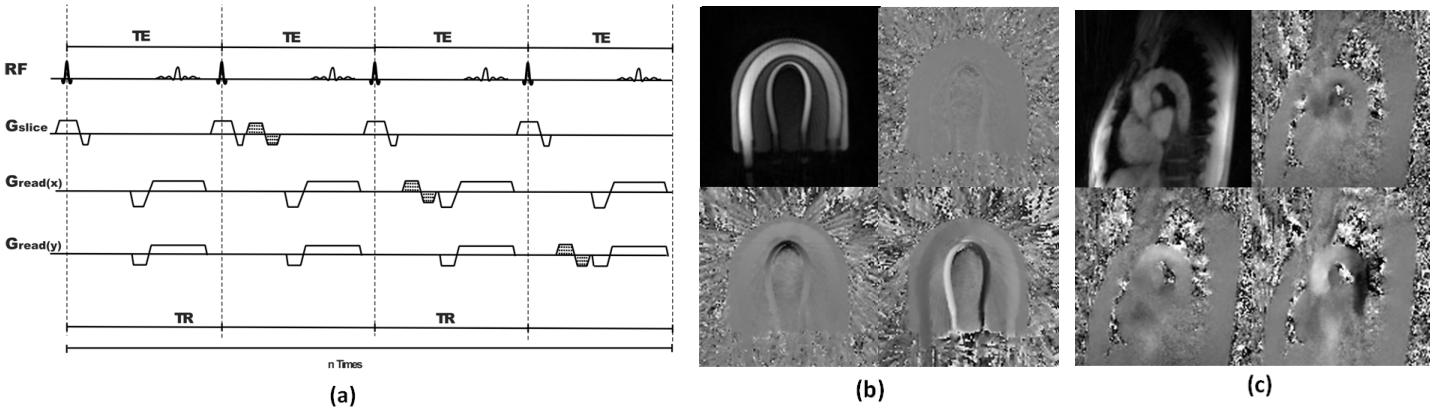

Figure 1: (a) Pulse sequence design of 3D PC MRI. Magnitude and phase contrast maps obtained from (b) invitro and (c) invivo studies. (Upper left) Magnitude image and phase contrast maps for different flow directions (upper right) perpendicular, (lower left) left-right, (lower right) head-feet.

Results and Discussion: Examples of the magnitude and phase contrast maps obtained from preliminary *invitro* and *invivo* studies are shown in figure 1. The magnitude and phase contrast maps, although obtained from highly undersampled data, have high SNR and minimal artifacts due to the robustness of radial sampling scheme in combination with the proposed reconstruction. The phase contrast maps of the phantom clearly show the expected phase difference pattern indicating a fast flow inside the smaller tube in the head-feet direction. A similar pattern is observed in the *invivo* studies of the ascending and descending aorta and the aortic arch during a systolic phase (Fig. 1c) selected from a continuous measurement over multiple heart cycles.

Conclusion: In this study, we have demonstrated that 3D-flow imaging can be realized by using highly undersampled radial FLASH and nonlinear inversion reconstruction. 3D-flow movies with a temporal resolution of 112 ms have been obtained. Presently, separate gradients are used for spatial and flow encoding but higher temporal resolutions can be achieved by combining pertinent gradient moments. No prospective or retrospective gating common for Cine 3D phase contrast flow imaging is needed for the proposed method.

References:

[1] Markl M et.al, JCMR 2011, 13:7
[2] Joseph AA et.al, NMRBiomed. 2012, 25:917-924.