Accelerated 4D Phase Contrast UTE MRI

Abdallah G. Motaal[1], Verena Hoerr[2], Huiming Dong[1], Luc M. J. Florack[3], Klaas Nicolay[1], and Gustav J. Strijkers[1]

[1]Biomedical NMR, Department of Biomedical Engineering, Eindhoven University of Technology, Eindhoven, North Brabant, Netherlands, [2]Department of Clinical Radiology, University Hospital of Muenster, Muenster, Germany, [3]Mathematics and Computer Science, Eindhoven University of Technology, Eindhoven, North Brabant, Netherlands

Purpose

Signal from short T2 components cannot be detected with conventional MR pulse sequences with echo times in the order of milliseconds as due to the relatively fast MR signal decay no magnetization is left during the readout. Several techniques such as ultashort echo time (UTE) MRI that makes echo times (TEs) in the range of 0.01 to 0.5 ms possible, enable the detection of very short T2 components[1]. Here, we introduce a MRI protocol for time resolved 3D UTE Cine Imaging. The sequence involves a retrospectively triggered 3D radial UTE MRI acquisition scheme that is performed asynchronously with the heartbeat, resulting in a randomly undersampled 4D k-space that facilitates compressed sensing reconstruction. 3D time resolved Cine movies with isotropic spatial resolution of 250 µm and 8 frames per cardiac cycle were achieved in 25 minutes with a very short TE of 8 µs that could help in detecting ultra-short T2 components. By incorporating flow encoding gradients, blood velocity could be estimated using phase contrast MRI with a very short TE of 0.68 ms. The sequence was validated and tested on a flow phantom and compared to the standard 3D FLASH based phase contrast MR sequence.

Methods

In-vivo MRI measurements were performed on 9.4T high field small animal MRI system with a horizontal bore of 20-cm with a 35-mm diameter mouse body quadrature volume coil in a 1 T/m gradient insert. Sequence parameters were: Block shaped RF pulse of 2 µs; flip angle = 5°; TR = 5 ms; TE = 8µs; number of spokes (NS) = 31400; field of view = 2.5 x 2.5 x 2.5 cm^2; isotropic acquisition matrix = 100; number of repetitions (NR) = 8. The resulting total acquisition time was NR x NS x TR ≈ 24min34s. Cine movies with 8 frames were reconstructed retrospectively, followed by compressed sensing reconstruction. The pulse sequence is shown in Fig.1. For retrospective triggering, a navigator slice is placed at the base of the heart. The navigator signal carries information needed to assign the acquired k-spokes to the corresponding time frame as shown in Fig.2. By choosing higher flip angles, more contrast between the blood and myocardium could be achieved, since there is very poor contrast between the blood and myocardium in UTE MR and 3D sequences in general. To validate phase contrast measurements, a customized flow phantom was used. The phantom is a cylindrical acrylic glass with four small tubes placed inside and connected to a peristaltic water pump as shown in Fig.3A. The pumping rate was ranging between v=0-400 cm/s. TE = 680 µs was achieved and hadamard encoding scheme was used resulting in total scan time of 12 min for 1 repetition. The proposed method is calibrated and compared with 3D FLASH based phase contrast MR.

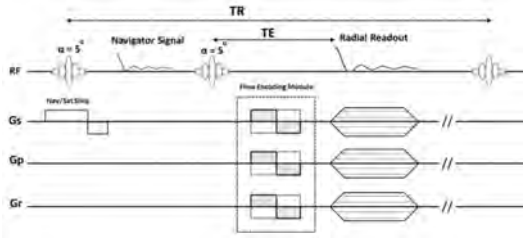

Figure 1: The Pulse Sequence Diagram. Separate navigator acquisition was done before every readout.

Results

In Fig.2, the top row shows the signal acquired from the navigator slice for the proposed retrospectively triggered 3D UTE sequence placed at the base of the heart. Clearly the cardiac cycle and respiratory phases could be distinguished. Based on the navigator signal, the data could be reconstructed retrospectively[2]. Because of the retrospective triggering and relatively short scan time for the 4D acquisition, the k-space is not fully acquired. However, accurate reconstruction could be achieved using compressed sensing method applied on the acquired undersampled k-space[3]. In Fig.2 the middle and the bottom rows shows the difference between linear and CS reconstructions of the murine abdomen for one of the time points in both the axial and coronal views.

Fig.3B shows an axial slice of the flow phantom used for phase contrast experiments. The corresponding flow map, providing calculated flow velocities, is shown in Fig.3C. The map shows hyper- and hypo-intense regions representing the in-/out water flow in the tubes. For calibration and validation, the experiments were carried out with different flow rates. The estimated velocities show linear relation with the input flow. There was an underestimation compared to the 3D FLASH flow maps, however, and because of the linear relation a calibration factor was added.

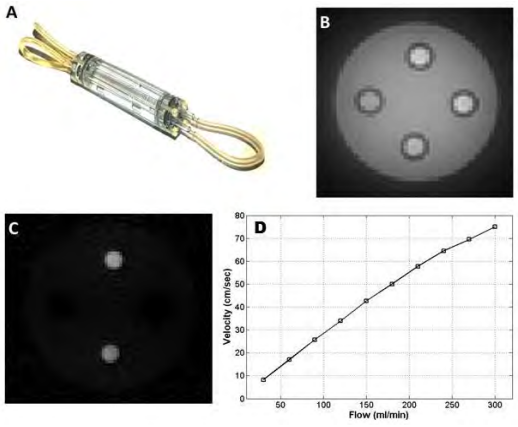

Figure 3: A) The used phantom with an B) axial slice from the reconstructed 3D volume. C) The phase map of the axial slice showing the in-/out flow of water. D) The estimated velocities show linear relation with the flow rate.

Discussion and Conclusion

In conclusion, a 4D UTE sequence is proposed to acquire full anatomical and flow maps with high isotropic resolution and short echo times that would help in better quantification. Although the 4D experiments suffered from long scan times, however, by using CS pipeline, reduction in scan time and reconstructions with less artifacts could be achieved.

The bipolar gradients, in the velocity encoding scheme, produce eddy currents that induce linear phase shift in the phase maps. For minimizing this effect, a delay between bipolar gradients and the start of the readout could be added, however this will affect the TR leading to longer acquisition time as well as TE leading to longer echo time. In the future work, invivo phase contrast experiments still have to be validated.

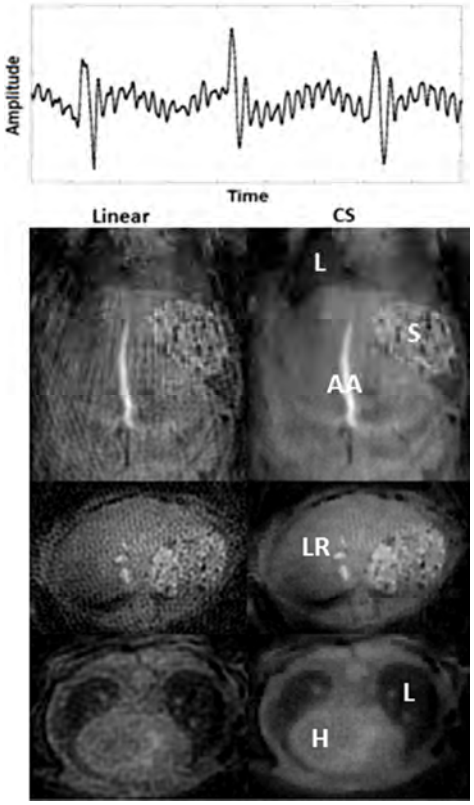

Figure 2: The top figure shows the navigator signal acquired. Clearly the cardiac cycle and respiratory phases are distinguished. The second, third and fourth rows show coronal and axial views of the abdomen (LR:liver, H:Heart, L:Lung, S:Stomach and AA: Abdominal Aorta) for a mouse using the proposed sequence with (left)linear and (right) CS accelerated reconstructions.

References

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2. Lustig et al. Magn Reson Med 58:1182–1195
3. Coolen et al. Magn Reson Med 69:648–65