USPIO enhanced 3D-cine Phase Contrast of the whole cardiovascular system in small animals at 7T with an Ultrashort Echo Time Sequence

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Target audience; This work is of great importance for studies involving measurements of blood flow velocities at high magnetic field and in small animal.

Purpose: In small animal studies, time-Resolved Phase Contrast sequences is mostly performed in 2D or in thin 3D volumes to obtain a high Time-Of-Flight effect and SNR using cartesian or stack of spiral/Ultra-Short Echo times (UTEs) sequences. This strategy is not applicable on the whole cardiovascular system with a 3D sequence due to the saturation of the spin into this volume which limits the study of abnormal blood flow in the aortic cross or in the descending aorta. To circumvent this problem, USPIO can be combined with UTE sequence to generate a high positive contrast at high magnetic field. However to use this strategy for 4D flow MRI, it is necessary to maintain a very short TE (< 0.6 ms). The goal of this study was to develop a time-resolved 3D UTE sequence with a very short TE. The method was combined with an USPIO injection to accuractely measure flow velocity in the whole mouse cardio-vascular system at 7T.

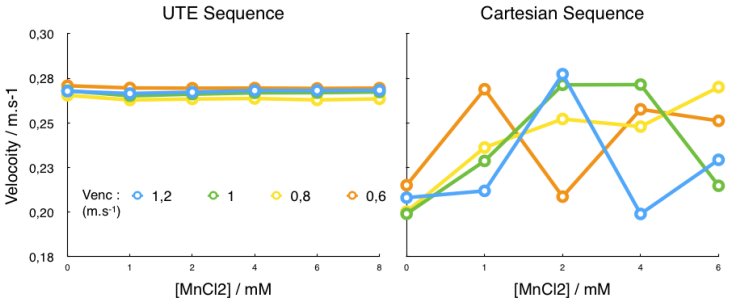

Figure 1. Comparison between FLASH and UTE sequences to measure flow velocity on phantom with various Velocity encoding values and increasing $MnCl_2$ concentrations.

Methods: A sequence based on a 3D UTE with a flow velocity encoding bipolar gradient after the excitation pulse was developed. Velocity was encoded with an hadamard method to reduce the gradient intensity. Flow velocity measurements were performed on a rectilinear tube at 7T. Average velocity was imposed at 25.8 $cm.s^{-1}$. The tube was filled with a solution of $MnCl_2$ at a concentration of 0/1/2/4/6/8 mM to mimic the increase of r_2^* due to USPIO in vivo on flow measurements. A UTE sequence with multiple Velocity Encoding (Venc) = 1.2/1.0/0.8/0.6 $m.s^{-1}$ were used. The pump flow was also modified to verify measurement linearity. Measurements were compared with a standard Phase Contrast Flash Sequence with the same parameters except TE/TR = 2.2/6 ms. A correction strategy[1] was applied on phase images to correct specific error in the UTE sequence. Flow quantification of the mouse cardiovascular system was performed with an injection of USPIO at a dose of 100 µmol Fe/kg with a new interlaced encoding velocity 3D time-resolved Cine triggered on ECG.

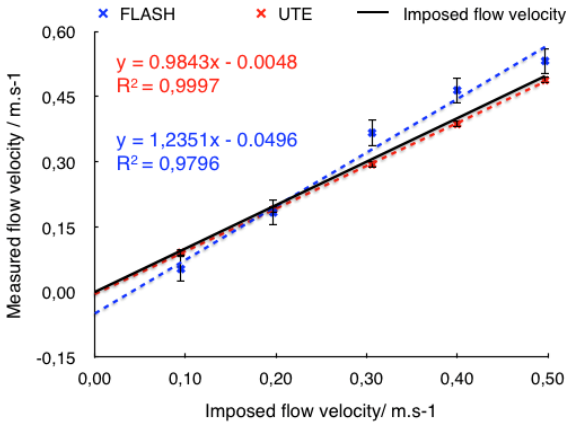

Figure 2. Comparison between FLASH and UTE sequences to measure various flow velocities on phantom.

Results: On phantom, with the UTE sequence, the maximum difference of the average velocity was inferior to 0,8 $cm.s^{-1}$ whatever the concentration of $MnCl_2$ or Venc values. FLASH sequence gave a maximum difference > 5 cm/s for a concentration superior or equal to 1 mM of $MnCl_2$ (figure 1). Furthermore, as seen on figure 2, flow velocity measurements showed a better linearity with the UTE sequence (R^2 = 0.9997) than FLASH (R^2 = 0.9796). On mouse heart, UTE sequence gave images without flow dephasing artefacts. Blood velocity vector map in the aortic cross is presented in figure 3. Flow vector can be visualized in various vessels (pulmonary/coronary/carotid arteries) and in any direction (Vx,Vy,Vz). Images were acquired in 45 minutes.

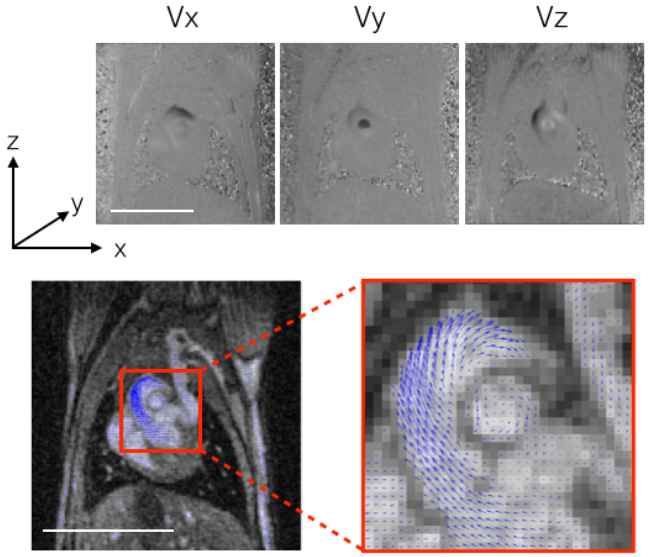

Figure 3. Phase velocity images and corresponding magnitude data with flow velocity vectors on aortic cross. (Scalebar : 10 mm)

Conclusion: A 4D flow UTE sequence with a very short TE was proposed. This was used to obtain a positive contrast of blood after injection of USPIO. These properties were exploited to produce high quality images and quantify blood flow velocity in the cardiovascular system in small animals at high magnetic fields with a high spatial < $(200\ \mu m)^3$ and temporal (16 ms) resolution. This approach might be useful to measure the functional cardiac parameters or to assess anatomical modifications of blood vessels or blood flow velocities in cardio vascular disease models. A new encoding strategy has been used to reduced errors due to cardiac movement.

References: 1. Chernobelsky et al : Baseline correction of phase contrast images improves quantification of blood flow in the great vessels. J Cardiovasc Magn Reson 2007;9:681-685.