Vastly undersampled time-resolved TOF MR angiography in mice with a prospective 3D radial double golden angle approach.

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Target audience; This work is of great importance for studies involving measuring blood flow velocities in small animal especially.

Purpose: Development of physiological and pathological small animal models in the field of vascular biology has increased. Blood velocity is a functional parameter useful to characterize the corresponding disease. However, it is not easily assessed noninvasively especially in small animals. Magnetic Resonance angiography (MRA) based on Time-Of-Flight (TOF) effect is a powerful method. A time-resolved cartesian TOF MRA method was developed but the total acquisition time required for 3D images with high spatial and temporal resolutions can be prohibitive[1]. The purpose of this work was to develop a time-resolved TOF MRA based on radial projection trajectories defined with a first golden angle (GA1) to obtain a uniform repartition along time and a second GA2 to obtain different trajectories between cine images. Spatial resolution was increased with this strategy by the use of a temporal filter. The efficiency of this method was performed on mice at 7T.

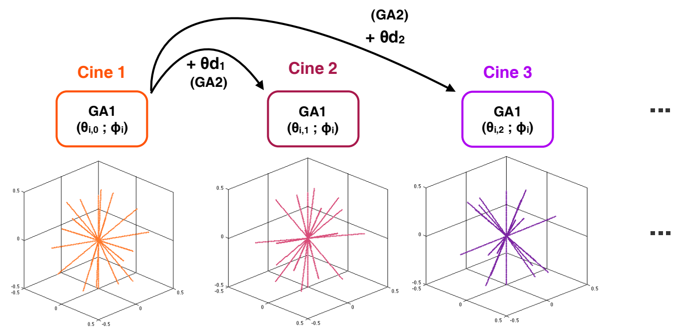

Figure 1. Modification of k-space trajectories between consecutive cine images.

Methods:

Sequence: This sequence was composed by a signal suppression module placed on the imaging volume applied when detecting a R-wave and followed by a cine radial FLASH.

K-space trajectories: Signal was acquired along projection defined by conventional spherical coordinates with 2D golden ratios[2]: $\theta_i = 2\pi \times (<0.6823 \times i>)$ $\phi_i = \mathrm{acos}(<0.4656 \times i>)$ where i was the projection's number. An approximately uniform distribution of projections was obtained over time. π was added to ϕ_i for odd values of i. Trajectories of cine differed by the rotation of all projections by an angle $\theta d_j = 2\pi \times (<0.4656 \times j>)$ where j is the cine's number (Fig. 1). This second golden angle allowed using a temporal filter during the reconstruction phase.

Reconstruction: To reconstruct a frame volume at a defined time, a temporal filter was applied to each cine. K-space data of adjacent cine were selected with an aperture in the radial direction depending on the temporal distance between the reconstructed and surrounding cine.

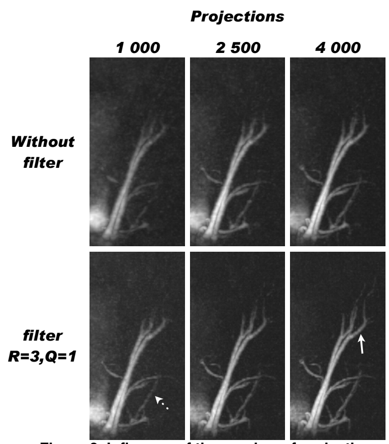

Figure 2. Influence of the number of projections and filtering on saggital MIP images of carotids, 51.64 ms after suppression module.

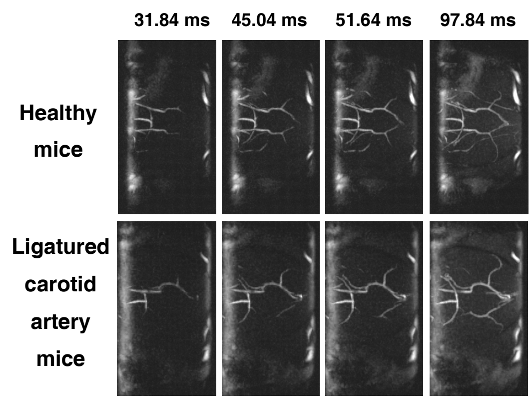

Figure 3. Extracted time-resolved coronal MIP images of blood flow in the Circle of Willis.

Results: Figure 2 shows a comparison of coronal MIP views acquired with 4000, 2500 and 1000 projections (Slice thickness=15mm, cine=30, TE/TR=1.5/3.3ms, Matrix= 192×192×128, FOV=25×25×25mm, BW=100kHZ) reconstructed with and without filter. Spatial resolution was clearly increased when using the filter as illustrated by the better delineation of the left internal and external carotids (white arrow) and the better detection of smaller vessels (dotted arrow). Spatial resolution was measured and shows an increase after using the filter. Blood volume and debit measures were equivalent between 2500+filter, 4000 and 4000 + filter reconstructions and overestimated due to a lack of resolution for the other reconstructions. Figure 3 shows 4 coronal MIP cine images extracted from the 30 images of a healthy mouse and a mouse with a ligatured left carotid acquired in 7 minutes. The high temporal resolution (3.3ms) of the cine images enabled to visualize the filling in of the Circle of Willis for both experiments as illustrated in figure 4. In ligatured mice, as only the right carotid was functional, a delay to fill the entire circle was clearly observed.

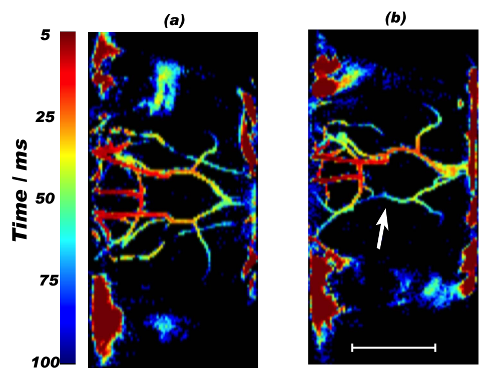

Figure 4. Time color-coded map of blood within the Circle of Willis in healthy (a) and carotid-ligatured mice (b).

Conclusion: This technique simultaneously provided high 3D isotropic spatial resolution, a high temporal resolution (< 4ms) with a good SNR level for blood flow visualization. Using the double golden angle approach, a temporal filter could be used to increase resolution and acquisition time was at least 4 times shorter than Cartesian approach for all the applications performed.

References: 1. Miraux et. al. Blood velocity assessment using 3D bright-blood time-resolved magnetic resonance angiography. Magn Reson Med 2006;56:469-473. 2. Chan et. al.: Temporal stability of adaptive 3D radial MRI using multidimensional golden means. Magn Reson Med 2009;61:354-363.