Improved Visualization of the Accelerated ASL-based Time-resolved MRA with Single Acquisition of Labeled and Control Images

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Purpose: Non-contrast 4D-MR angiography (4D-MRA) using arterial spin labeling (ASL) is a valuable technique in the diagnosis of several neurovascular diseases such as intracranial dural arteriovenous fistulas (AVFs)[1]. However, ASL 4D-MRA requires acquisition of labeled and control images to generate the angiographic images, which doubles the scan time. Recently, we introduced a 4D-MRA technique that acquires labeled and control images in a single Look-Locker like multiphase acquisition, halving the scan time compared to the conventional ASL technique[2]. However, this single acquisition technique sometimes suffers from lower SNR due to a limited labeling slab thickness. In this work, we further optimized this technique to counter these limitations and acquire data with similar image quality as the conventional ASL technique.

Methods: The basic sequence diagram is illustrated in Fig.1. The Hyperbolic Secant (HS) labeling pulse is applied prior to the second phase read-out. Image acquired in the first phase do not have labeled blood so are used for a control image. In the second and later phases, labeled blood that flows to the periphery is depicted. 4D-MRA is generated by subtracting images all labeling phases from the single control phase. The main limitation of this technique is that any suppression pulses which affect the tissue signal should not be used as they increase the background signal after subtraction. This limitation causes fat inside the imaging volume to be labeled by the chemical shift of the labeling pulse, resulting in bright fat signal in the subtracted images (Fig.2 left).

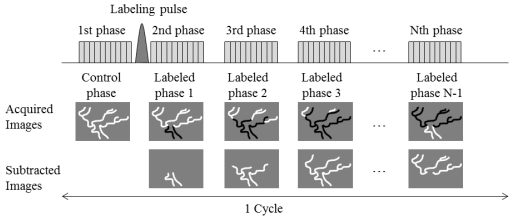

Fig.1 Sequence diagram of the single acquisition technique

Another limitation is that MT effects from the labeling pulse cannot be compensated because the control pulse is not used. Therefore, it is not ideal to use high RF energy for the labeling pulse. Considering both limitations, optimization of the labeling pulse was performed by (1) reversing the volume selection gradient to reverse the chemical shift direction and (2) optimizing the labeling pulse. The HS inversion pulse is given by an amplitude modulation $A(t) = A_0(t)\mathrm{sech}(\beta t)$, and frequency modulation $\Delta\omega(t) = -\mu\beta\tanh(\beta t)$. The pulse was optimized by changing angular frequency (β), scaling parameter (μ) and RF energy to reduce the chemical shift and MT, whilst maintain the labeling efficiency. Inversion profile was analyzed by Bloch equation simulations and several combinations of RF pulse parameters were tested in three healthy volunteers. All scans were performed on a Philips 3.0T scanner with 3D TFEPI sequence with imaging parameters following: FOV = 220 mm, Matrix = 176 x 176, slice thickness = 0.65 mm, 140 slices, SENSE factor = 2.5. TE/TR = 4.9/ 9.3 ms, EPI/TFE factor = 5/13, flip angle = 10°. A control image and 9 labeled images with delay between 42 ms to 1642 ms were acquired with interval of 200 ms. Scan time was 3:18. For comparison, 4D-MRA using conventional ASL technique was also acquired with same imaging parameters, and its scan time was 6:36.

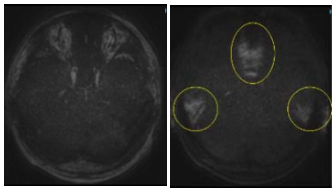

Fig.2 Fat signal with default selection gradient (left) and artefact from the tissue around the sinus with reversed selection gradient (right)

Results and Discussion: Although reversed gradient suppressed the fat signal effectively, signal around the sinus elevated (Fig.2 right) due to B0 inhomogeneity. Before optimization of β and μ, the maximum labeling slab thickness which did not pose the artefacts was 80 mm with 20 mm gap between labeling and imaging volume. This thin labeling caused decreased visualization in later phases (Fig.4(a)). Doubling μ halved the chemical shift and allowed the use of a 160 mm labeling slab without artefacts, dramatically improving the visualization of arteries in later phases. However, due to the decreased labeling efficiency, signal intensity of arteries was slightly reduced. Fig.3 shows the signal intensity of the left and right M1 area and background tissue acquired with different nominal flip angle between 750° to 1200°. Although the signal intensity was elevated by increased RF energy, the background signal was also increased due to MT effect. Besides, chemical shift was increased again due of prolonged pulse duration under limited maximum allowed B_1 of 3T clinical scanner, and started to show the artefacts again with flip angle of 1200° (data not shown). However, images acquired with flip angle of 900° (Fig.4(b)) showed improved visualization of arteries with minimal artifact, data which is very similar to the 4D-MRA acquired using the conventional ASL technique with even thicker labeling slab (Fig.4(c)).

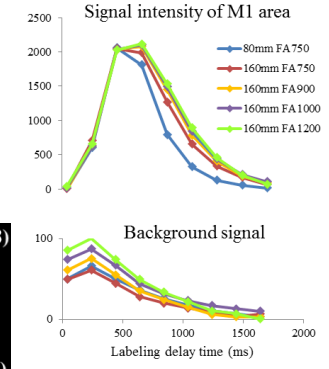

Fig.3 Signal intensity of M1 area (upper) and background tissue (lower) with different RF energy.

Conclusion: We showed our single acquisition technique which enables the scan time halved could generate 4D-MRA image with very similar quality with the conventional ASL technique, making it suitable for acute cases. Application of the adiabatic pulses such as VERSE[3] or BASSI[4] which has smaller chemical shift with superior profile and less RF energy is considered for further improvement.

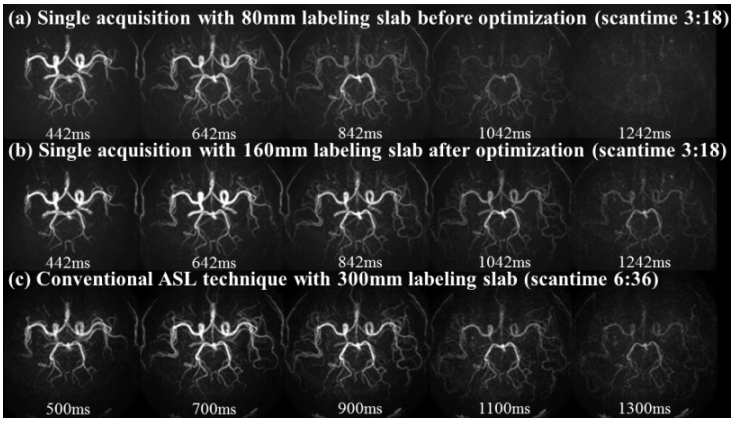

Fig.4 Representative comparison of 4D-MRA images

References: 1. Iryo, Y. et al., Radiology 2014; 271: 193-199, **2.** Suzuki, Y. et al., *Proc.ISMRM* 2013, **3.** Conolly, S. et al., MRM 1991; 18:28-38, **4.** Warnkin, JM. et al., MRM 2006; 55:865-873