Optimizing T1w-SPACE for intracranial arterial imaging

Lei Zhang[1], Jaeseok Park[2], Jun Wu[3], Xin Liu[1], and Yiu-Cho Chung[1]

[1]*Paul C. Lauterbur Center for Biomedical Imaging, Shenzhen Institutes of Advanced Technology, Chinese Academic of Sciences, Shenzhen, Guangdong, China,* [2]*department of brain and cognitive engineering, Korea university, Seoul, Korea,* [3]*Neurology, Peking University Shenzhen Hospital, Shenzhen, Guangdong, China*

INTRODUCTION: Intracranial atherosclerosis is a major cause of ischemic stroke. Vessel wall imaging can detect atherosclerotic plaques undergoing positive modeling easily missed by luminal angiography. Vessel wall imaging of intracranial arteries (ICA) is challenging because ICAs are small and cerebrospinal fluid (CSF) surrounding the vessel walls (esp. mid cerebral arteries, MCA) are usually bright. T1 contrast is desired in ICA wall imaging because it shows gadolinium induced signal enhancement of the plaques that is related to the plaques' vulnerability [1]. In 3T clinical imaging, 3D TSE variants VISTA [2] and T1w-SPACE [3], which employ variable flip angles in the refocusing pulse train, can be potentially well adapted but still remain sub-optimal for this application. Thus, this approach needs to be further optimized to enhance the signal intensity of vessel wall while suppressing that of CSF. To achieve this aim, in this study we propose to adapt the T1w-SPACE by utilizing a new series of tissue-specific signal prescription based refocusing flip angles and accordingly modified imaging protocols. Simulations and in vivo experiments reveal that the proposed approach is to improve the depiction of intracranial arterial walls (especially MCA) bathed in CSF.

MATERIALS & METHOD: Pulse sequence: The sequence was based on [4] where the refocusing pulses' flip angles were optimized for a prescribed signal evolution of grey matter at 1.5T (T1/T2=940ms/100ms). At 3T, T1 values increase, and such design is suboptimal in terms of SNR. Simulation also found that the flip-down pulse in [4] improved T1 contrast at the expense of SNR. Here, T1w-SPACE for high resolution ICA imaging was optimized in two ways. (1) Increase the flip angles for the refocusing pulses for better SNR. This is done by using T1/T2=1000ms/150ms in flip angle series calculation. The new flip angle series (fig. 1b) gave stronger echoes. (2) Take advantage of the higher signal in (1), reinstate the flip-down pulse in [4] to improve T1 contrast between MCA vessel wall and surrounding CSF. Simulation was performed to help understand the effect of the two changes on signal and contrast compared to [4]. The "modified T1w-SPACE" was implemented on a 3T MRI system (Magnetom TIM Trio, Siemens, Germany).

Experiments The studies were IRB approved. Informed consents were obtained from both healthy volunteers and patients. A 32-channel head coil was used for signal reception. In a healthy volunteer, images for T1w-SPACE, modified T1w-SPACE with and without flip-down pulse were acquired upon localization. GRAPPA was not used. Next, 4 patients (3 male, 47~56 years old) diagnosed with stenosis of intracranial artery based on earlier MRA/CTA findings were recruited for examination. After spatial localization, MRA and DWI were performed. T1w-SPACE and modified T1w-SPACE with flip-down pulse were scanned. Imaging parameters for T1w-SPACE were: TR/TE=935/25ms, ETL=35, 64 partitions. For modified T1w-SPACE, TR/TE=1250/30ms, ETL=45, 60 partitions. GRAPPA rate 2 was used in the patient study. Spatial resolution = $(0.5\text{mm})^3$ for all scans. Scan time = 10min. No contrast was used.

Analysis: In the healthy volunteer, the SNR and contrast to noise (CNR) between WM (T1 and T2 values similar to vessel wall [5]) and CSF from the three T1w-SPACE images were measured. In the patient study, the contrast ratio between the plaque and CSF were measured (the spatially varying noise due to GRAPPA makes direct noise measurement impossible).

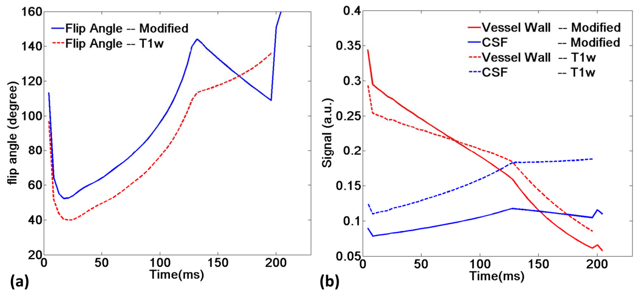

Fig.1: (a) Refocusing pulses' flip angles series for T1w-SPACE (T1/T2 = 940/100ms) and modified T1w-SPACE (T1/T2 = 1000/150ms); (b) signal evolution of vessel wall and CSF for T1w-SPACE and modified T1w-SPACE. Note the higher signal at the start of echo train and the lower signal for CSF.

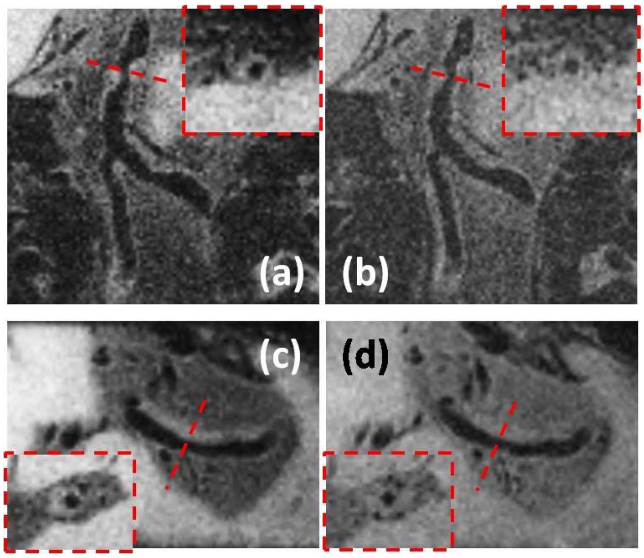

Figure 2: Images of a patient from modified T1w-SPACE and T1w-SPACE. (a) Basilar artery and (c) middle cerebral artery from modified T1w-SPACE; (b) and (d) were the corresponding arteries from T1w-SPACE. The arterial walls in both territories were better delineated in modified T1w-SPACE.

RESULTS: Simulation results were shown in Fig.1. In the volunteer study, the SNR of WM/CSF for T1w-SPACE, modified T1-SPACE without and with flip-down pulse were 44.2/22.5, 51.2/24.8 and 48.5/17.1 respectively. The CNR between WM and CSF was 21.7, 26.4 and 31.4 accordingly. In patients, the averaged contrast ratio between vessel wall and CSF for T1w-SPACE and the modified T1w-SPACE with flip-down pulse was $10.9\%\pm4.6\%$ and $30.8\%\pm6.7\%$ respectively at the MCA territory (e.g., Fig.2d vs 2c). At the basilar artery (BA) region, the respective averaged contrast ratio was $37\%\pm28.6\%$ and $51.3\%\pm48.6\%$ (e.g., Fig.2b vs 2a). All images in Fig.2 were windowed to the same level to facilitate contrast comparison.

DISCUSSIONS: The volunteer study showed that SNR was improved with the modified T1w-SPACE. Use of flip-down pulse reduced the SNR slightly but improved the contrast between WM and CSF. In patients, the contrast improvement from the use of flip-down pulse was obvious. The results were consistent with the simulation in Fig.1b. Note that contrast improvement was more consistent at the MCA region than at the BA region. This may be due to CSF flow variation among individuals around BA region. The results showed that the T1 contrast between intracranial wall and surrounding CSF in both MCA and BA territory were improved in the modified T1w-SPACE. The flip-down pulsed increased the signal difference between vessel wall and CSF with a small but obvious SNR penalty. The application specific T1/T2 values used for the refocusing flip angle series calculation recovered the lost SNR. The net result on the image was that intracranial arterial wall was better delineated without compromising spatial resolution and scan time. The technique will be very useful in clinical imaging of intracranial atherosclerotic plaques.

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