3D Variable-Flip-Angle TSE with Prospective Self-Gating of Swallowing Motion: Initial Experience in Carotid Artery Wall MRI

Zhaoyang Fan[1], Petter Dyverfeldt[2], Xin Liu[3], Sven Zuehlsdorff[4], Vibhas Deshpande[5], David Saloner[2], and Debiao Li[1]

[1]Cedars-Sinai Medical Center and University of California, Los Angeles, CA, United States, [2]Departments of Radiology and Biomedical Imaging, University of California, San Francisco, CA, United States, [3]Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, China, People's Republic of, [4]Siemens Cardiovascular R&D, Chicago, IL, United States, [5]Siemens Healthcare, San Francisco, CA, United States

Introduction: 3D black-blood MRI is a promising technique for carotid artery wall assessment but is inherently susceptible to motion (1). Previous work has shown that swallowing can result in the greatest motion at the carotid bifurcation and its vicinity (2). A self-gating (SG) method in combination with a 3D variable-flip-angle turbo spin-echo (TSE) sequence, SPACE, has been proposed for prospectively gating swallowing motion (3). Briefly, during each TR, a cross-correlation coefficient (*CC*) between the imaging volume projection profile and corresponding reference profile is calculated. If it is less than a pre-defined threshold (TH_{cc}), apparent motion is detected and the data will be discarded and reacquired in the following TR. This work aimed to test the utility of the SG-SPACE technique on healthy volunteers and patients.

Methods: Eight healthy volunteers (3 M, age 29 ± 8 years) and 14 patients with suspected carotid atherosclerosis (12 M, age 68 ± 8 years) were recruited in the study. All volunteers and two patients were scanned at 3.0T (MAGNETOM Trio; Siemens) using a bilateral 4-channel carotid coil (Machnet BV). The rest of the patients were scanned at 1.5T (MAGNETOM Avanto; Siemens) using a custom-design bilateral 8-channel carotid coil. All healthy subjects underwent the following three oblique coronal scans using SG-SPACE: a) imaging without swallowing instructions or SG ("SPACE STL"); b) imaging with swallowing instructions but without SG ("SPACE SWL"); c) imaging with both swallowing instructions and SG ("SPACE SWL+SG"). In the "SPACE SWL" and "SPACE SWL+SG" scans, subjects were instructed over the intercom to swallow twice at five preset stages, namely the 30th, 50th, 60th, 70th, and 90th TR of the 120-TR scan. All patients underwent only two scans, SPACE without and with SG, without swallowing instructions. The relevant imaging parameters included: TE/TR 141 msec/3 R-R intervals (3.0T) or 2500 ms (1.5T), readouts and SG-projection in the craniocaudal direction, isotropic resolution 0.7-0.8 mm, acquisition time 120 TRs per scan in the absence of motion. Image quality and vessel delineation were graded on a 5-point scale (0, very poor wall delineation or unusable images; 4, excellent wall delineation with little or no wall boundary blurring). Vessel wall sharpness was also measured in volunteer studies.

Results: Seven healthy subjects (14 carotids) who had successful scans were included in data analysis. In general, swallowing motion resulted in severe blurring of artery wall boundaries, impaired wall continuity, and reduced wall-tissue contrast on non-gated images, which were dramatically improved by SG (**Fig. 1**). Retrospective SG projection analysis revealed that data acquired in 27 ± 22 TRs was discarded due to detected motion. Image quality and wall boundary sharpness with "SPACE SWL+SG" were compared to those with the two other scans (**Table 1**). The image score obtained in the "SPACE SWL+SG" scan was significantly

Table 1. Image quality (0: worst – 4: best, t-test) and sharpness (Wilcoxon's test) obtained from "SPACE SWL+SG" are compared with those obtained from the two other scans.

	Image Quality		Sharpness of Carotid Wall Boundary (mm^{-1})			
	Score	*p*-Value	Outer Boundary	*p*-Value	Inner Boundary	*p*-Value
SPACE STL	3.2 ± 0.6	0.002	2.02 ± 0.28	0.232	1.86 ± 0.24	0.121
SPACE SWL+SG	2.4 ± 0.7	N/A	1.95 ± 0.27	N/A	1.78 ± 0.24	N/A
SPACE SWL	1.1 ± 0.5	0.001	1.73 ± 0.37	0.003	1.56 ± 0.36	< 0.001

higher than that obtained in the "SPACE SWL" scan, although it was significantly lower than that obtained in the "SPACE STL" scan. Moreover, the sharpness of wall boundaries was preserved by exploiting SG with the "SPACE STL" scan as a reference, but it significantly deteriorated when swallowing was not gated.

Ten patients who had successful scans were included in image quality evaluation. Motion was detected by SG in every patient. The number of discarded TRs was 77 ± 53. Improved image quality by SG-SPACE over regular SPACE was observed (2.6 ± 1.1 vs. 1.7 ± 1.3, Wilcoxon's test *p* = 0.01). **Fig. 2** shows in a patient who had random occurrences of shortness of breath, regular SPACE images were essentially non-diagnostic, whereas the SG-SPACE technique dramatically improved the image quality and the lesions were much better depicted.

Discussion: In healthy volunteers, swallowing was shown to induce severe overall image degradation, obscure wall boundary, and reduce the wall-to-background contrast. The SG approach significantly mitigated the above problems. Further, in comparison with regular SPACE imaging without swallowing instructions, the SG-SPACE sequence provided slightly impaired yet acceptable image quality and statistically comparable wall boundary sharpness in the presence of swallowing events. Motion of the carotid artery is expected to be complex in patients and considerable improvement in image quality has been observed in 5/10 patients by SG. Further evaluation of its utility in improving disease diagnosis accuracy is underway. It is concluded that the proposed SG technique has the potential to enhance the clinical value of 3D black-blood MRI in evaluating carotid atherosclerosis.

References: 1. Balu N et al. JMRI 2008; 27:918.   2. Boussel L et al. JMRI 2006; 23:413.   3. Fan Z et al. ISMRM 2010; 3695.
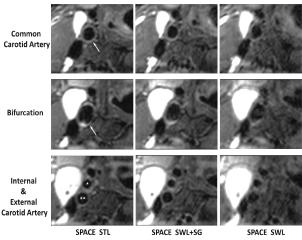
Fig. 1. Comparison of transversal MPR images obtained from the SPACE STL, SPACE SWL+SG, and SPACE SWL scans, respectively, in an 18 yo female volunteer. The proposed SG approach significantly mitigates the swallowing-induced artifacts, including blurred wall boundary and reduced wall-to-background contrast. *, external carotid lumen; **, internal carotid lumen.
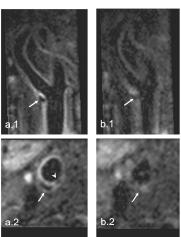

Fig. 2. The SG-SPACE images (a.1 and a.2) of a 75 yo male patient with a history of transient ischemic attack and random occurrences of shortness of breath demonstrate an atherosclerotic plaque at the bifurcation of the right carotid artery (arrows). Calcification and thin fibrous cap in the shoulder region (arrowhead) are clearly depicted. However, severe motion artifacts in regular SPACE imaging (b.1 and b.2) result in non-diagnostic image quality.