Dual Imaging with Bright Blood Arterial Input Function and Black Blood Tissue Acquisition for Vessel Wall Imaging in Atherosclerosis: BB-SHILO (Black-Blood Simultaneous High-Low Temporal (Low-High Spatial) Resolution Imaging)

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Introduction: Recently, Dynamic Contrast Enhanced (DCE) Magnetic Resonance Imaging (MRI) has gained interest in assessment of plaques in atherosclerosis in the carotid arteries (1,2). It is widely acknowledged that to measure the kinetic parameters accurately requires accurate measurement of the tissue uptake curve (Ct) and the arterial input function (AIF) (3). Current DCE-MRI methods extract Ct and AIF information from the same image data. This is sub-optimal for the carotid arteries where the vessel wall should be imaged with high spatial resolution, shows weaker signal enhancement than the vessel lumen, and requires slower temporal sampling than the first pass of the AIF. Dual imaging techniques (4-8) acquire the AIF and Ct data in separate images, acquired either separately in a dual-bolus approach, with a low-dose AIF scan preceding the high-dose tissue scan; or simultaneously, with one injection of the higher dose required for imaging uptake in the tissue.

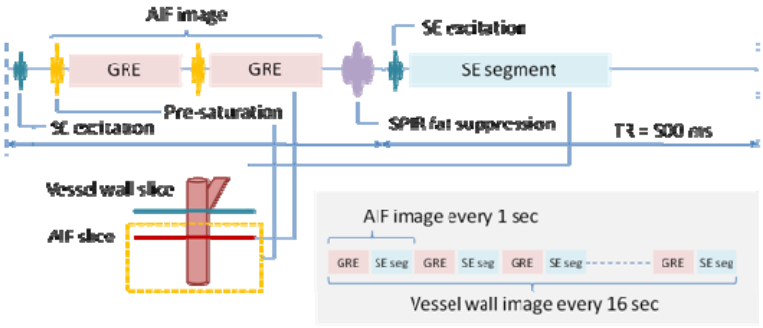

Fig. 1: Pulse sequence diagram of black-blood SHILO showing two TR intervals comprising one AIF image and one SE segment. Grey insert shows repetition of TRs for one SE vessel-wall image, which is then repeated for DCE imaging.

AIF acquisition requires bright-blood contrast, and is thus acquired with T1-weighted gradient-echo based sequences. Conversely, in the carotid arteries, dark-blood acquisition is desirable to eliminate bright lumen obscuring often thin vessel wall features (1). In order to investigate the benefits of simultaneous dual imaging for the carotid arteries, the purpose of this work was to implement and assess the feasibility of a new sequence that interleaves gradient echo acquisitions with segmented spin-echo acquisitions, allowing high temporal resolution acquisition of low spatial resolution bright-blood images for the AIF acquisition, and higher resolution dark-blood images of the vessel wall. This sequence builds on that reported by Calcagno et al. (4) dubbed SHILO (Simultaneous High-Low Temporal (Low-High Spatial) Resolution Imaging).

Methodology: The proposed sequence timing diagram is shown in Fig. 1. A saturation-prepared segmented radiofrequency spoiled GRE AIF image acquisition is played prior to every spin-echo segment acquisition. SE-acquisition is free to have high resolution and multi-slice coverage as well as phase-ordering independence including centric re-ordering and SENSE acceleration. The target vessel wall slices are placed around the carotid bifurcation; the AIF slice and the spatially-selective AIF-saturation pulse is moved caudally to both prevent perturbation of the tissue slices and saturate inflowing blood in the AIF slice. To maintain magnetisation steady state in the target slices (SE acquisition), the SE excitation pulse flip angle is set to 90° and is played prior to every AIF acquisition with a repetition time TR.

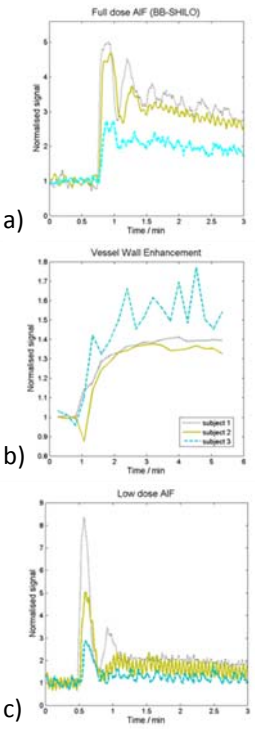

Fig. 2: BB-SHILO normalised signal - time curves: a) AIF, b) vessel wall uptake curves; c) low dose test bolus AIF

With written informed consent, three subjects were imaged with BB-SHILO following administration of a full clinical dose of 0.1 mmol/kg of Gd-DTPA (Magnevist) flushed by 20 ml saline injected at 4 ml/sec, (FOV 160 mm, 2D slice perpendicular to the common carotid artery, vessel wall: matrix 320x320, pixel size 0.5x0.5 mm, TR=500 ms, echo train length 20, centric reordering, single slice, temporal resolution 16 sec; AIF: matrix 320x80, pixel size 0.5x4 mm, TR=4.2 ms, TE=2.5 ms, FA=15°, linear phase-ordering, temporal resolution=1 sec; 3 T, Philips Achieva system) giving a total of 320(AIF) / 20(vessel wall) image frames spanning 5.3 minutes. To compare the shape of the AIF function, prior to full dose DCE, an AIF was acquired with a single-shot GRE sequence (same parameters as BB-SHILO AIF except matrix 160x160, pixel size 1x1 mm) following a test dose of 0.01 mmol/kg. Signal-time curves were found by taking the average signal in ROIs placed on the vessel lumen (AIF) and vessel wall. For BB-SHILO, kinetic parameters were estimated and compared to literature values to establish feasibility of the strategy. The signal was assumed linear to concentration, and parameters K_{trans}, v_e, v_p and k_{ep} were estimated using a modified Tofts model. In addition, one subject was imaged with a fat-suppressed (SPIR) multi-slice BB-SHILO variation (images not shown). Partial-Fourier and SENSE acceleration were employed to image 4 vessel-wall slices with a temporal resolution of 20 sec (all other parameters as previously except, AIF: pixel size 0.5x2 mm, TR=5.5 ms).

Results: Typical AIF curves from BB-SHILO with full dose and single-shot GRE with a test dose are shown in Fig. 2 showing the feasibility of SHILO for AIF acquisition. The difference in shape is attributable to the non-linear signal-concentration relationship at high CA concentration - this should be addressed in separate work. DCE uptake in the vessel wall is also shown in Fig. 2b. Image quality from the segmented GRE and SE acquisitions is demonstrated in Fig. 3 showing a bright-blood AIF image frame and a black blood vessel wall image - the latter shows effective blood suppression and visualisation of CA uptake in the vessel wall. Kinetic parameters estimated with BB-SHILO DCE are summarised in Table 1 and are consistent with literature values (9,10), demonstrating the feasibility of BB-SHILO for simultaneous acquisition of AIF and multiple vessel wall slices with good temporal resolution (20 sec) at full clinical dose of contrast agent.

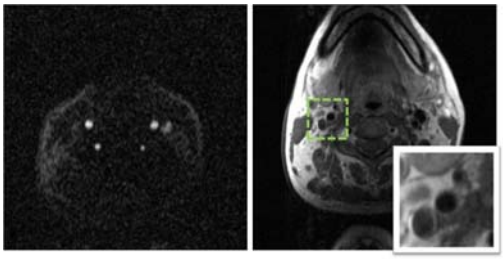

Fig. 3: AIF (left) and vessel wall images (right) from BB-SHILO dual-imaging acquisition. Detail shows uptake in the vessel wall and suppression of vessel-lumen signal.

Table 1: Kinetic parameters measured with BB-SHILO

Parameter	Range	Mean ± SD
K trans	0.121 - 0.416	0.240 ± 0.16
k ep	0.558 - 0.776	0.656 ± 0.11
v e	0.217 - 0.657	0.370 ± 0.25
v p	0.0 - 0.105	0.0445 ± 0.054

References: 1) Calcagno et al., ATVB 2008;28(7):1311-1317; 2) Kerwin et al., Radiology 2006;241(2):459-468; 3) Parker et al., 1996-ISMRM:p.1582; 4) Calcagno et al., 2011-ISMRM:p.3316; 5) Kim et al., JMRI 2006;23(1): 81-86; 6) Jelescu et al. JMRI;33(6):1291-1300. 7) Gatehouse et al., JMRI 2004;20(1):39-45; 8) Wang et al., 2011-ISMRM:p.1234; 9) Kerwin et al., MRM 2008;59(3):507-514; 10) Yankeelov et al., MRI 2005;23(4):519-529.