Depiction of SPIO in atherosclerotic plaque using true resolution SGM

G. Varma[1], M. R. Makowski[1], H. Dahnke[2], S. Keevil[3], R. M. Botnar[1], and T. Schaeffter[1]

[1]Division of Imaging Sciences, King's College London, London, United Kingdom, [2]Philips Healthcare, Hamburg, Germany, [3]Medical Physics, Guy's & St Thomas' NHS Foundation Trust, London, United Kingdom

Introduction: Detection of atherosclerotic plaque with iron oxide contrast agents (e.g. SPIO) that induce a susceptibility effect in MRI is sometimes hindered by competing sources of negative contrast. There is also the characteristic blooming artefact associated with dephasing in the presence of SPIO. Solutions utilising MR sequences to convert the hypo-intensities into a positive contrast often require refinement of the scan parameters and are in addition to any negative contrast scans. Utilising the off-resonance effect of an iron oxide contrast agent, saturation of the on-resonant signal using the IRON technique has been used in detection of atherosclerotic plaque [1]. Similarly the local magnetic field gradients in the presence of iron oxide have been exploited by GRASP to indentify plaque with positive contrast [2]. Although these positive contrast methods aid in detection, hyper-intensities are often over-emphasised and may thus fail to accurately depict the plaque. Post-processing methods also exist to produce positive contrast images by mapping the effect of susceptibility-like field gradients in gradient-echo acquisitions [3-4]. The technique of susceptibility gradient mapping (SGM) uses a "short term" FT i.e. a FT using a small finite extent in *k*-space resulting in a map that arguably has a lower resolution [3]. Positive contrast images have more recently been calculated at the same resolution by looking at the signal intensity drop associated with successive truncation of k-space lines to determine any echo-shifting effect [4-5]. However such a truncation and consequent zero filling results in Gibb's ripple artefacts that may affect mapping of the echo-shift. We present a modification of the method outlined in [4] that uses a filter to provide a consistent truncation line-by-line. This method can be seen not only to provide a more robust shift determination since it does not require additional reconstruction algorithms, but also producing positive contrast images for better localisation of susceptibility sources as it retains the original resolution of the acquired data.

Theory: Susceptibility induced field inhomogeneities alter the imaging gradients applied during a gradient echo acquisition. Such local field inhomogeneities are also created in the presence of SPIO and thus result in a displacement of the associated echoes in *k*-space. Determining the shift in *k*-space thus allows a parametric map to be created that relates the local susceptibility-induced field gradient to its corresponding pixel. SGM utilises short-term FTs at each pixel across its neighbours to determine the shift. It therefore requires a compromise between the spatial resolution and the accuracy to which the shift is expressed. Our alternate technique for locating this shift involves applying a filter based on a 1-Lorentzian function applied across, for instance, the k_x-direction. The Lorentzian function (i.e. of the form $1/[(1/T_2^*)^2+(k_x-k_{xo})]$) used to form the filter is based on a relatively long T_2^* value representing minimal line broadening and then applied in a sliding window fashion so that only a single line of defined k_x-value is completely at zero. This continues line-by-line moving from $-k_{max}$ to $+k_{max}$ so that only a single line is completely at zero and thus producing $(2*k_{max})+1$ images. Plotting the intensity of each pixel from these images against the k_x line that is truncated to zero shows a drop at the *k*-space centre. In the case of voxels influenced by SPIO that have their echo-shifted along the k_x-direction, the intensity minima provides a measure of the shift (Fig.1). For a 3D dataset, this procedure is repeated along all spatial dimensions to produce a parameter map of each pixel's related shift in *k*-space. A magnitude image of this map therefore positively highlights susceptibility changes within the original dataset.

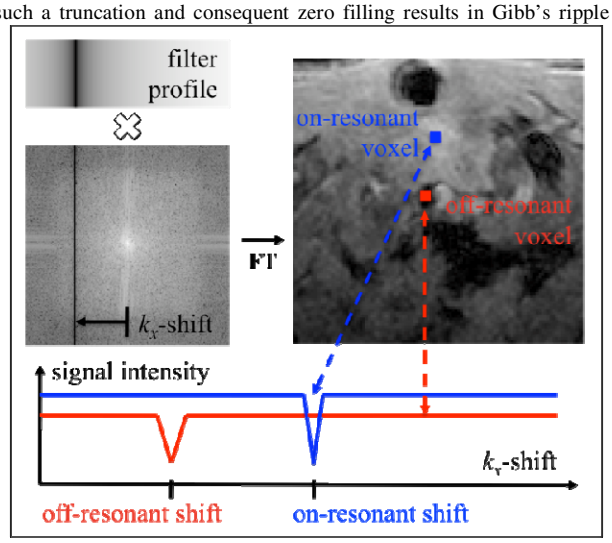

Fig.1. Lorentzian based filter profile is applied along k_x-direction in sliding window approach. FT of the filtered k-spaces produces images from shift values of $-k_x$ to $+k_x$. Minima in plots of the signal intensity variation with k_x-shift for each pixel are used to determine the echo shift and produce the associated parameter map.

Materials and Methods: ApoE-KO mice were fed a high-fat diet for 8 weeks to induce a model for atherosclerotic plaque around the brachiocephalic artery [6]. At day 0 and day 1 they were tail-vein injected with a 250µl/kg dose of VSOP, and then imaged on day 2. This allowed sufficient time for the VSOP to circulate and for uptake by macrophages to occur at the site of inflammation. Scanning was performed on a 3T Philips Achieva whole-body scanner using the 23mm Philips microscopy coil. ECG triggered 3D gradient echo datasets were collected with: flip angle=25°; FOV=16x16x8mm; in-plane resolution=120µmx120µm; matrix =176x176x20; TE=6.9ms; TR=21ms.

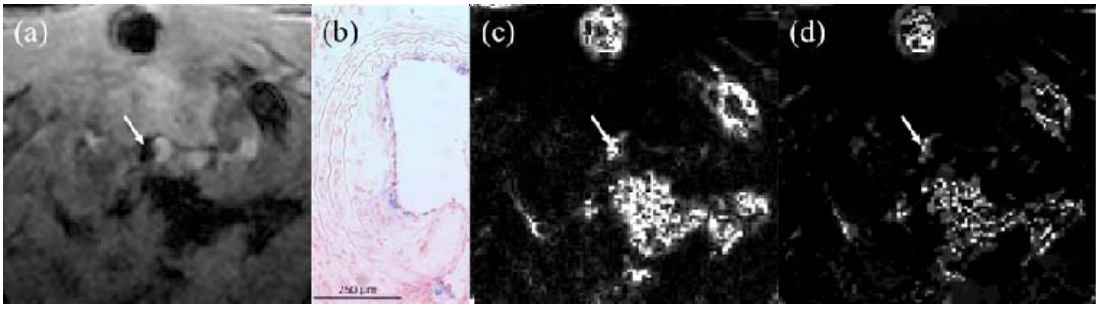

Fig.2. Slices taken through the brachiocephalic artery. (a) VSOP uptake at site of plaque implied by dephasing (arrow). (b) Histological image shows lesion build up from wall into vessel with iron stained blue. Scale bar = 250µm. (c) SGM of data used to produce image in (a). (d) Positive contrast image from line filling with zero to determine echo-shift in *k*-space.

Results: Negative contrast images were obtained from the 3D gradient echo acquisition and showed a distinct negative contrast around the brachiocephalic artery (Fig.2a). This related well to the position of the plaque in histology of a slice through the brachiocephalic artery, in which the lesion had built up inside of the wall of the vessel (Fig.2b). Application of SGM to the same slice produced a positive contrast that coincides with the region of dephasing seen in the negative contrast image (Fig.2c). The positive contrast observed in Fig.2d was produced using the true resolution technique and also shows hyper-intensities that correspond to the contrast change observed in Fig.2a and Fig.2c.

Discussion and Conclusions: The hypo-intense region observed around the vessel of interest (Fig.2a) indicates VSOP uptake at the site of plaque build-up. Although both methods of positive contrast post-processing successfully depict this region, the extent of contrast in the SGM closely resembles dephasing in Fig.2a. However the delineation of positive contrast in Fig.2d more closely resembles the effect expected from histology, since it's crescent shape is observed to encompass the circularity of the artery. This is attributable to the method achieving a positive contrast by determining the shift relating to each pixel as opposed to SGM, which relies on examining the echo-shift using short-term FTs that result in neighbouring voxels sharing in the susceptibility effect. The "true resolution" method has thus been shown to provide a more accurate depiction of the SPIO induced susceptibility effect with relation to its source.

References: [1] Korosoglou *et al*, JACC 53:999-1005(2005). [2] Mani *et al*, MRM 56:1096-1106(2006). [3] Dahnke *et al*, MRM 60:595-603(2008). [4] Dahnke *et al*, ISMRM 1513(2008). [5] Chen *et al*, NeuroImage 31:609-622(2006). [6] Johnson *et al*, Circulation 111:1422-1430(2005).