Use of susceptibility mapping to detect suspicious dark rim artefacts during perfusion MRI

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Introduction: First pass myocardial perfusion MRI following the intravenous bolus injection of gadolinium-based contrast agents can be used for the non-invasive detection of coronary artery disease [1-2]. However dark band or rim artefacts along parts of the subendocardial border are a common problem in first pass perfusion studies, which can be mistaken for perfusion defects, in particular by less experienced observers. The source of these artefacts has been attributed to magnetic susceptibility associated with the high concentration of the contrast agent during the first pass [3-4]. In this work we show that the use of high-resolution susceptibility gradient mapping (SGM) [5] helps to distinguish between perfusion defects and susceptibility induced artefacts. The high-resolution SGM technique uses the first pass perfusion data and thus requires no additional data acquisition.

Method: A high concentration of paramagnetic contrast agent can result in local susceptibility gradients between the blood signal and the myocardium. Depending on the spatial resolution and echo time such additional magnetic field gradients can result in dark rim artefacts due to geometrical distortions of the affected voxels within the image [6]. Furthermore, such local susceptibility gradients result in a shift of the associated echo-top in *k*-space [7]. Recently a SGM technique has been proposed to determine the echo-shift for each pixel of the complex (real and imaginary) image data at the same spatial resolution [5]. This method developed from another, truncating different parts in *k*-space and looking for its effect on the intensity of each pixel [8]. A disadvantage of this is the influence of Gibbs-ringing artefacts for large amounts of truncation. In contrast to this, and as an alternative to [5], we applied a filter that is based on a 1-Lorentzian function, such that single lines along a direction in *k*-space were nulled completely to determine the shift. Fourier transform of the filtered *k*-space data into image space results in signal intensity drops within pixels relating to the shift in *k*-space and the associated echo-top. Thus recording the shift in *k*-space for each direction at which signal intensity drops provides a parameter map of the related susceptibility gradient for each pixel.

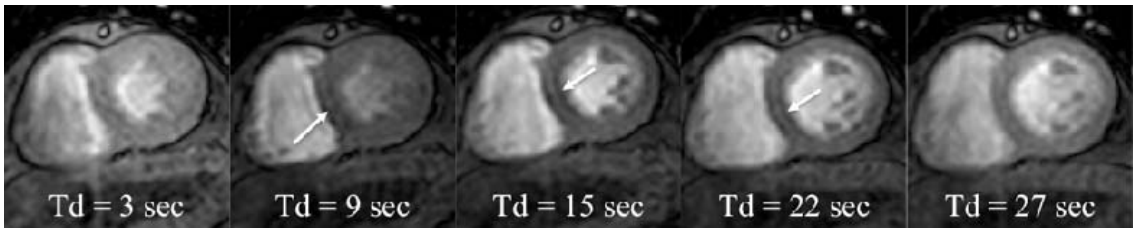

Fig.1. A selection of dynamic cardiac MR images acquired, 185ms after the R-R wave, with ECG triggering. The dynamic time (Td) immediately relates the acquisition time after bolus injection of Gd-DTPA contrast agent.

Experiments: Dynamic complex (real and imaginary) gradient echo datasets were acquired in 4 patients undergoing clinically indicated perfusion imaging on a 3T MR scanner (Philips Achieva). Following the clinical perfusion studies, an additional perfusion acquisition was performed for this study. Data were acquired with intravenous bolus injection of 0.1mmol/kg Magnevist (Bayer Schering Pharma AG, Germany) with: dynamics = 40; flip angle = 20°; FOV = 350x340mm; matrix = 136x128; no. of slices = 2; slice gap = 6.0mm; slice thickness = 8.0mm; TE/TR = 1.39/3.00ms Susceptibility gradient maps (SGM) were determined from the image data in post-processing using the method described above.

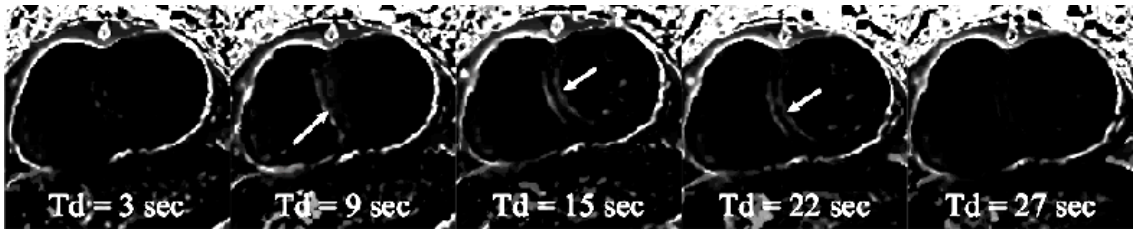

Fig.2. A form of susceptibility mapping applied to the dynamic cardiac data based on determining the echo-top shift in *k*-space relating to each pixel. The magnitude of the SGM positively highlights suspicious magnetic susceptibility gradients.

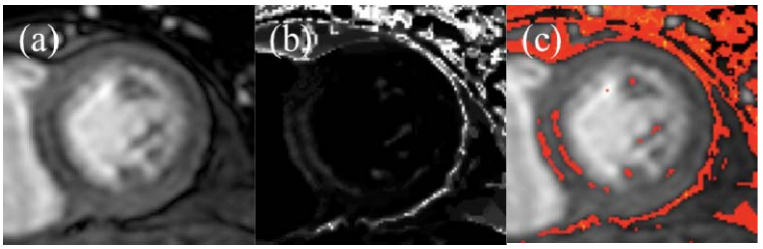

Fig.3. (a) Short-axis gradient-echo image at Td=19s showing a dark rim artefact. (b) Magnitude image from SGM of the gradient-echo data corresponding to (a). (c) Threshold of SGM in (b) to show shifts greater than 4 pixels overlaid in red onto gradient-echo MR image to highlight location of suspicious susceptibility gradients coinciding with dark rim.

Results: Suspicious endocardial dark rims suggestive of artefacts were observed on the perfusion images in 3 of 4 patients. In all 3 cases the dark bands were also detectable by threshold of the parameter map from SGM and overlay onto the original image data. Fig.1 shows a representative selection of images from the dynamic series, demonstrating the passage of the contrast agent through the right ventricular cavity at Td=9s, and passing into the left ventricular cavity from Td=15s onwards. A dark rim is visible within the subendocardium in the images obtained at Td=15 and 22s. Fig.2 shows the corresponding SGM for the same time points formed from the perfusion image data. Again at Td=15 and 22s, a line of hyper-intensity is observed relating to the dark rim artefacts observed in Fig.1. Fig.3 shows the perfusion image at Td=19s, the magnitude SGM and an overlay of the threshold SGM onto the first pass perfusion image providing additional information for analysis of perfusion defects. A second dark rim artefact is highlighted on the right ventricular side of the septum. Its appearance in Figs.1 and 2 at Td=9s, before the effect of the Gd-DTPA reached the left ventricular cavity, may thus be perceived as a susceptibility effect from the contrast agent in the right ventricular cavity.

Discussion and Conclusions: The use of SGM allows the detection of susceptibility gradients. It is still open to question whether the dark rim artefacts are due to susceptibility from the contrast agent or other sources of off-resonance [4,7]. Positive contrast observed at the edges of the heart may be attributed to the susceptibility gradient from water/fat or tissue/air interfaces and remain visible throughout the dynamic series. However the dark rim from Td=9 to 15s in Fig.1, and the corresponding hyper-intensities from the SGM in Fig.2, observed at the interface of the myocardium and ventricular cavity supports the notion that susceptibility associated with Gd-DTPA plays some part in the source of the dark rim artefacts. SGM after threshold and overlaid onto the original perfusion data (Fig.3c) may have clinical value by alerting those reading the study to the possibility of an artefact. Since formation of the positive contrast post-processing image only relies upon the complex image data of the gradient-echo scan, this method may be implemented without the need for any additional scans.

References: [1] Nagel *et al*, Circulation 108:432-437(2003). [2] Plein *et al*, European Heart Journal 29:2148-2155(2008). [3] Arai, Topics in MRI 11:383-398(2000). [4] Ferreira *et al*, MRM 60:860-870(2008). [5] Dahnke *et al*, ISMRM 16:1513(2008) [6] Di Bella *et al*, MRM 54:1295-1299(2005). [7] Posse *et al*, MRM 25:12-29(1992). [8] Chen *et al*, NeuroImage 31:609-622(2006)