Stent visualization by susceptibility field mapping using the original resolution

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Introduction

MRI is becoming an alternative modality to guide and assess deployment of endovascular stent grafts. Visualization of these metallic devices in MR is traditionally based on local susceptibility gradients that result in rapid dephasing of the spins and thus hypo-intensities in the vicinity of the stent [1]. However signal voids may be confused with other sources, such as areas of low proton density or turbulent flow, making assessment of deployment sometimes difficult. Techniques have been proposed to change the negative to a positive contrast [2]. In particular, susceptibility gradient mapping (SGM) has been used to visualize stents in a post-processing step [3]. SGM forms a parameter map of the susceptibility gradient using a short-term FT for each pixel over a small number of adjacent pixels. However Vonken et al. showed that SGM requires a relatively high resolution (< 1mm) to ensure a constant gradient over the spatial extent used in the short-term FT.

In this work, we have used a new technique to allow SGM using the original spatial resolution. This technique is based on correction of EPI field distortions proposed by Chen *et al.* to calculate k-space shift k_s by applying a filter and analyzing the effect on each pixel separately [4,5]. This technique was modified with an improved filter design and applied for nitinol stent-graft visualization.

Theory

Chen *et al.* truncated successive lines of k-space along one direction whilst evaluating the signal amplitude at each pixel in the corresponding image to calculate k_s. To avoid Gibb's ringing artifacts in the FT of truncated k-space, a filter $F(k,k_o)=1-(\Delta k/(\Delta k^2+(k-k_o)))$ that nulls a single line at position k_o is proposed. Figure 1 illustrates the effect of *F(k,ko)* for susceptibility gradients in the k_x and k_y directions against a homogeneous background. When k_o=k_s the signal in the FT is reduced. Thus k_s is located by the signal minimum in a plot of the signal amplitude for all possible filter positions k_o at each pixel. For pixels with small signal intensities the influence of the filtering *F(k,ko)* is expected to have a minor effect. Therefore, after filtering, pixels with a signal drop smaller than 5 times the standard of the noise are excluded.

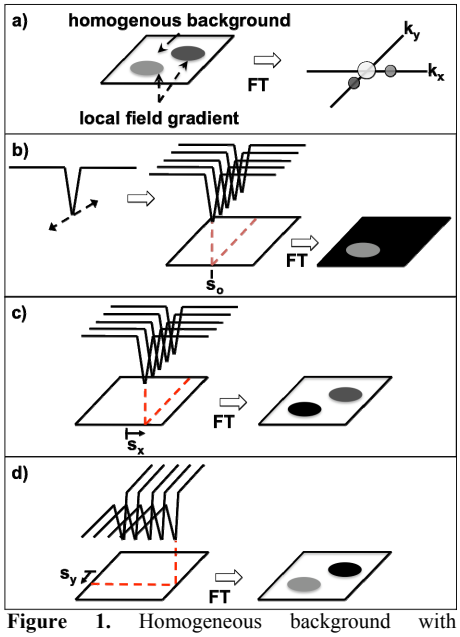

Figure 1. Homogeneous background with susceptibility gradients and FT shows shift in k-space (a). *F(k,s$_o$)* along k_x removes un-shifted background (b). For *F(k,s$_x$)* signal at gradient drops. (c) *F(k,k$_o$)* is applied separately in each direction, i.e. *F(k,s$_y$)* shows drop in signal with shift in k_y (d).

Method

MR data from a gelatin phantom with a GORE TAG® (Gore Medical) stent graft was obtained on a clinical 3.0T scanner (Philips, Achieva) using a 6 element cardiac coil. MR images with different resolutions of 1, 2 and 3 mm (isotropic) were obtained (FOV=240x240x60mm^3; FA=25^o; TE/TR=3.1/6.5ms). The influence of spatial resolution on the k-space shift was investigated by calculating the average $|k_s|$ in a ROI and plotting this against the distance across one edge of the stent. In addition, data from a patient with aortic dissection was also used to positively visualize the stent-graft: An ECG triggered respiratory navigated IR prepared gradient-echo sequence was conducted (acquisition resolution=1x1.5x3mm^3; FOV=251x400x156mm^3; FA=20^o; TE/TR=2.7/5.6ms) after injection of a blood pool agent (Vasovist^{TM}, Bayer Schering Pharma AG). The positive contrast was formed from the magnitude parameter maps of the k-space shift, $|k_s|$. The positive contrast image was visualized as an overlay (in red) on the gradient-echo images without registration using OsiriX Imaging Software. The standard deviation of the k-space shift, σ_{ks} was determined in the background to define a threshold for the overlay.

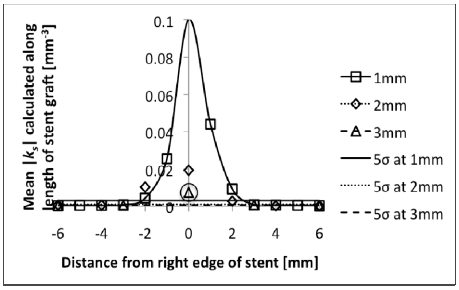

Figure 2. Plot of mean $|k_s|$ calculated along edge of stent against distance across its edge.

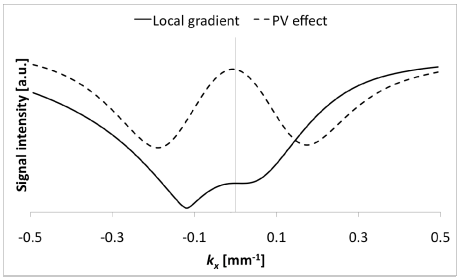

Figure 3. Plot of signal response from application of *F(k,k$_o$)* for different values of *k$_o$=k$_x$*. A symmetrical response occurs in presence of PV effects. A single minimum is due to susceptibility.

Results and Discussion

A positive contrast from the stent-graft was observed at all 3 resolutions *in-vitro* (Fig.2). However for low spatial resolution (3mm) only a single pixel (circled) achieved a hyper-intensity above the 5σ_{ks} level. This suggests the 3mm^3 resolution as a lower limit for detection, whereas SGM using a short-term FT would fail due to the effect existing over just one pixel. Due to the acquisition resolution of 3mm^3, a partial volume (PV) effect can be expected in voxels relating to the presence of the nitinol wire frame making up the stent. This was assessed in a plot of pixel signal intensity against the value in k-space k_o set to null by the filter F(k,k$_o$). PV effects can be differentiated from those solely due to a local gradient by the symmetry of their signal compared to asymmetric dephasing conditions from magnetic susceptibility effects [6]. Figure 3 illustrates the two minima located around k_s=0 relating to PV effects (dash), whereas a symmetric signal plot is attributed solely to the susceptibility gradient (solid). The patient data shows that positive contrast overlay can be used to visualize the proximal apposition of stent-graft to the wall as well as to assess the distal extent and length of the device (Fig.4).

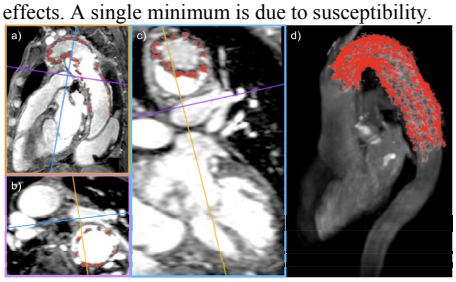

Figure 4. Overlay of positive contrast from $|k_s|$ map in red onto original data. The stent is visualized in different planes from MPR and in 3D by overlay onto scan for MR angiography.

Conclusions

The modified technique for determining k_s allows positive visualization of the nitinol wire frame in the stent and may be extended to depict similar devices. Exploring the signal response from application of the filter shows PV effects. In maintaining the original resolution, information from both contrasts is combined without registration to analyze placement of the device.

References

[1] Eggebrecht *et al*. J. Endovasc. Ther. 2006 13:62-71; [2] Varma *et al*. MAGMA 2009; [3] Vonken *et al*. MRM 2008 60:588-594; [4] Chen *et al*. NeuroImage 2006 31:609-622; [5] Dahnke *et al*. Proc. ISMRM 16:1513 (2008); [6] Seppenwoolde *et al*. MRM 2007 58:605-609