Enhancing Referenceless Phase Sensitive Reconstruction using Geometry Based B0 simulation

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Purpose:

Compared to magnitude images, phase sensitive MR images offer higher dynamic range as the magnetization polarity is restored[1]. Referenceless Acquisition of Phase-sensitive Inversion-recovery with Decisive reconstruction (RAPID) imaging was recently proposed[2], as a time-efficient alternative to the Phase Sensitive Inversion Recovery (PSIR), to reconstruct phase-sensitive images without the need for reference acquisitions. RAPID achieves phase sensitive reconstruction by eliminating the background phase variations (largely introduced by B0 variations) and restoring the underlining phase change introduced by magnetization polarities. The RAPID algorithm, however, may be subject to errors when the image SNR is low and/or the underlining B0 change is severe[2]. Encouraged by recent advancements in water-fat imaging[3], a geometry based B0 estimation algorithm[4] is incorporated into RAPID to help mitigate these B0-related phase changes and potentially improve the robustness of RAPID algorithm.

Methods:

MR Scan and Data Analysis   10 patients with suspected cardiac disease were scanned with the standard PSIR imaging protocol using a 5-ch cardiac coil and whole body 1.5T scanner (Philips Achieva R3.2, Best, the Netherlands). The imaging parameters were: 2D IR-TFE, IR interval 2RR, TFE factor 16, TR/TE 7.5/4.6ms, FA 15°, TI 230-250ms, FOV 360×360mm², resolution 1.5×1.5mm², slice thickness 10mm. Complex images S(r) were exported from the MR scanner for RAPID reconstruction. Standard PSIR images were also exported as a reference to evaluate RAPID's performance.

Geometry based B0 mapping   A large portion of the B0 variations are commonly caused by the intrinsic body susceptibility induced magnetic field perturbations. These perturbations can be simulated using established electromagnetic theory, as has been previously demonstrated[4]. In our case, a 3D tissue contour based susceptibility map χ(r) of the imaged anatomy was first generated based on the signal intensity on magnitude images and prior knowledge of the body geometry that was scanned. To simplify the process, only water-air susceptibilities (-9.05ppm and 0.36ppm, respectively) are considered in generating χ. The susceptibility induced background phase ψ(r) can then be obtained using methods referenced[4].

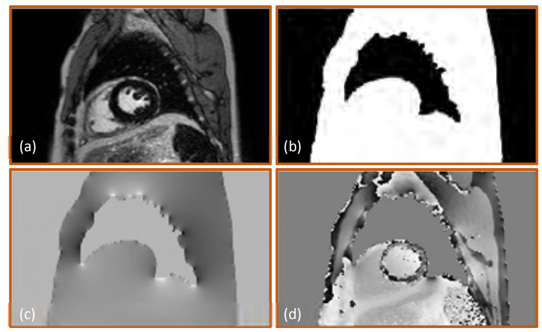

Fig. 1 B0 assisted RAPID. Body contour (b) was generated based on the magnitude image (a). After calculating the susceptibility introduced B0 map (c), the phase map (d) of the B0 compensated image (Scor) can be obtained.

RAPID reconstruction and evaluation   To mitigate the impact of B0 variations, the simulated phase ψ(r) was demodulated from image S: $S_{cor} = Se^{-j2\pi\psi TE}$, where S_{cor} is the B0 compensated image while S is the original image (Fig.1). In order to evaluate the impact of using the simulated B0 map, the RAPID algorithms were implemented on the acquired images both with (S_{cor}) and without (S) B0 compensation. A difference map was generated by subtracting phase-sensitive images generated by RAPID and that by PSIR.

Results and Discussions:

Out of the 10 subjects included in this study, the RAPID reconstruction was found to present certain level of discrepancies compared to the PSIR image in 3 subjects. B0 assisted RAPID, however, was able to correctly restore the magnetization polarity in all these cases.

As shown in Figure 2, the discrepancies identified on regular RAPID images (arrows) were all successfully corrected on B0 assisted RAPID images (Fig. 2a&c).

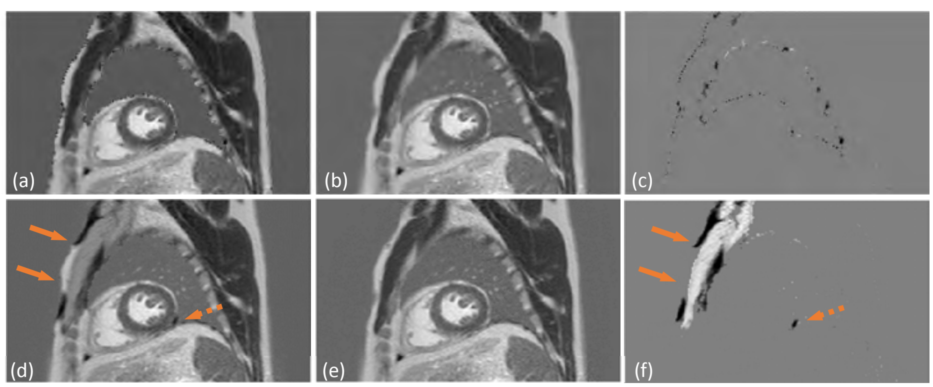

Fig.2 Comparison between B0 assisted RAPID (a-c) and regular RAPID (d-f). Images a&d are phase-sensitive images from RAPID with/without the body susceptibility correction, respectively; b&e are the same PSIR image; c&f are the difference between RAPID and PSIR images. All the discrepancies identified on regular RAPID image (d&f, arrows) were successfully removed on B0 assisted RAPID images

The RAPID algorithm can confuse a large background phase variation from true phase changes between opposite polarities. Once the background phase is demodulated using simulated information, B0 assisted RAPID becomes more robust at challenging geometry locations: e.g. locations with more than one chemical species (solid arrows in Fig. 2d) and large susceptibility locations (dotted arrows in Fig. 2d). One pitfall of the B0 simulation algorithm concerns phase errors around the water-air contours, as can be seen in Fig. 2c. This is caused by the zigzag boundary shape when digitizing the binary body contour. This can be potentially minimized by using extra tissue interface-driven smoothing when the B0 map is simulated. These areas are known to be prone to small errors because the underlying assumptions of the field prediction method are violated [4]. Further effort is necessary so sort out some small local signal swaps.

Conclusions:

In this work, B0 assisted RAPID reconstruction algorithm was developed and tested in vivo. Without any extra acquisition, geometry based B0 simulation was found to improve the robustness of RAPID algorithm.

References: 1. Borrello JA et al. MRM 1990; 14:56-67 2. Wang J et al. MRM 2014; 72:806-15 3. Sharma SD et al. MRM 2014 (e-pub ahead of print). 4. Koch KM et al. Phys. Med. Biol. 2006; 51:6381-402