Slice Offset Frequency Adjustment (SOFA) for SSFP Imaging

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Introduction

Steady-state free precession (SSFP) imaging is a popular technique for rapid imaging due to the inherent high signal-to-noise ratio (SNR). However, this advantage comes at the price of susceptibility to off-resonance artefacts. In order to minimise such effects the scanner centre frequency (f0) should match the Larmor frequency at the location of the imaging slice. Usually scanner vendors provide a method of automatically determining the centre frequency but this is generally only performed at isocenter, with the patient table being moved such that the centre of the stack of prescribed slices is moved to this location. The variation in static magnetic field homogeneity means that f0 for slices away from isocenter will be incorrect and will consequently demonstrate greater artefacts than those slices nearer isocenter. This work investigates the change in f0 with slice position along the z-axis of the scanner and establishes an empirical relationship between f0 and position. This relationship is then used to calculate a slice offset frequency adjustment (SOFA) for each slice in a multi-slice stack. Each frequency adjustment is then used to correct the scanner f0 prior to acquiring that slice.

Methods

A standard spin echo sequence was modified by removing the gradients on the phase and frequency encoding axes thereby allowing a non-spatially encoded spin echo signal to be obtained from each slice position. The spin echo from each slice in a multi-slice prescription was then allocated to a "phase-encoding" position within the raw data array, i.e. the number of "phase encoding" steps equalled the number of slices. Each echo comprised 256 data points acquired with a bandwidth of ±2.1kHz. Thirty-two 12mm slices were prescribed axially on a uniform quality assurance phantom, covering a z axis distance of ±192mm. The actual slice locations were written out to a separate file. With a TE/TR of 67/120ms the calibration scan took 3.84s. The raw MR data was then analysed in Matlab (1D FFT followed by peak detection) to obtain the frequency shift correction for each slice position, assuming that there was no correction required for the slices at isocenter. A fifth order polynomial was then fitted to the frequency shift/slice location data. An SSFP sequence (FIESTA, GE Healthcare, Waukesha, WI) was then modified to read the polynomial coefficients and calculate the frequency offset for each slice location. Using the Larmor frequency for isocenter, obtained during prescan, the sequence then calculated the frequency offset for each location and updated the scanner f0 register just prior to acquiring that slice.

The modified sequence was used to obtain multi-slice axial images in a uniform phantom and normal volunteers using the previously acquired SOFA correction data. The method has also been implemented as part of an interactive MRI controller [1] to ensure that the optimal f0 is used for any real-time scan location.

Results

Figure 1 shows the frequency offset as a function of position obtained in a uniform phantom and the fit of a fifth order polynomial to the data. Figure 2 shows images obtained in a phantom with and without the SOFA correction. Note a significant reduction in artefact in slices away from isocenter. Figure 3 shows three images obtained, at slice location +149.7mm, in a normal volunteer a) without the SOFA correction, b) with the correction and c) the same slice but moved to isocenter to demonstrate the correct Larmor frequency determination by the scanner prescan algorithm. Whilst the improvement is not as visually apparent as in the phantom images the SOFA corrected image gives very similar results to the section acquired at isocenter and shows marked reduction in off-resonance artefacts when compared to the uncorrected image acquired at the same offset location (arrows).

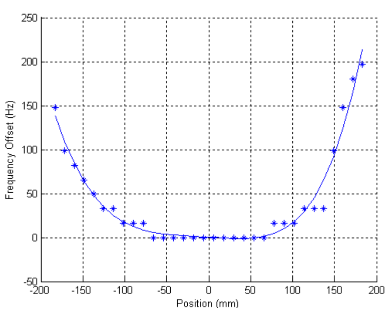

Figure 1. Centre frequency offset as a function of Z-axis position relative to isocenter for SOFA calibration with 5th order polynomial fit (line)

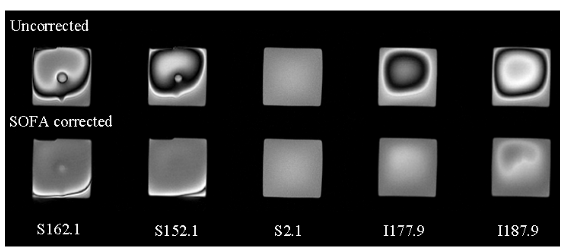

Figure 2. Phantom images obtained with (bottom row) and without (top row) SOFA correction. (Slice positions in mm are given below the images)

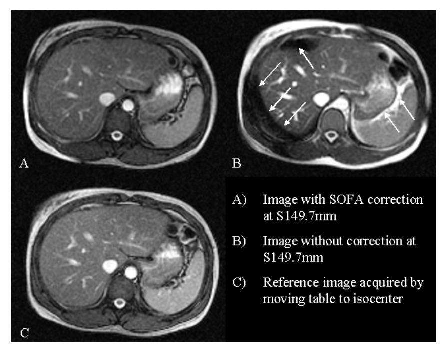

Figure 3. In vivo images with off-resonance artifacts (arrowed) on the uncorrected image (B) compared with the corrected image (A) and the same slice scanned at isocenter (C).

Conclusion

This work demonstrates that correcting the f0 on a slice by slice basis reduces off-resonance artefacts in SSFP imaging. In this work a pre-computed set of correction coefficients obtained from a phantom is sufficient to provide an improvement in image quality without having to perform the correction on a per patient basis. Further work will investigate corrections in the X and Y directions.

References

[1] Lomas DJ et al, Reference surface constrained navigation controller for 3D image data & real-time MRI. Proc. Intl. Soc. Mag. Reson. Med 724 15 (2007)

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