Combining Slice Dependent Center Frequency Adjustment and High Order Eddy Current Correction for Improved Multistation Diffusion Weighted Imaging

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INTRODUCTION

Diffusion weighted echo planar imaging (DW-EPI) is very sensitive to B0 field offset and eddy currents. Except for the localized tissue susceptibility (difficult to remove) and chemical shift (removed by chemical saturation pulses), other B0 field offsets (e.g., magnet inhomogeneity, shim error) are often smooth in space, creating slice-dependent bulk image distortion. Eddy currents in DW-EPI are primarily generated by the diffusion gradients. Although the linear and constant eddy currents are typically well corrected in preemphasis, residual high order eddy currents (HOEC) can still generate large, diffusion direction dependent image distortion/blurring, especially for the Stejkal-Tanner sequence [1], which is widely used in body and high resolution brain imaging due to the high signal-to-noise ratio it provides. B0 and eddy current distortions are even worsened in multistation DW-EPI (e.g., whole body DW imaging), where the unmatched distortions at station boundaries can create sharp geometric and intensity discontinuities, largely degrading image quality and making image pasting very difficult if still possible. We propose to use a combined HOEC and slice-dependent B0 offset correction to reduce image distortion, bulk shift, and station discontinuity (if multiple stations are used). The HOEC correction is based on a previous work described in [2]. The B0 offset correction is a slice dependent center frequency (CF) compensation method. Unlike the approach in [3] where CF offset is calibrated from the EPI reference scan, in this paper we use extra free induction decay (FID) signal collected after the excitation pulse at each slice to estimate CF offsets. The new approach is advantageous when a reference scan is unavailable. A 2-station phantom study shows that the combined correction method is capable of reducing station boundary discontinuities as well as slice shift trend. The proposed method can be particularly useful in multistation whole body DW imaging, although it is also applicable to single station imaging.

PROPOSED METHOD

Before each scan, protocol dependent eddy currents are first calculated based upon the results from eddy current calibration and gradient shape/timing [2]. Then we collect an FID signal after the 90 degree excitation pulse (before the refocusing pulse if spin echo sequence is used) at each slice during the "dummy" scan (preparatory scan often available to help reach magnetization steady state). This signal is Fourier transformed to obtain the overall B0 offset at its corresponding slice, which determines the amount of CF compensation. Note the above calculation is instantaneous and implemented through communicating with a real-time server. The slice dependent CF offsets are then smoothed through filtering and polynomial fitting for robustness consideration. For the subsequent sequence repetitions involving imaging data collection, we apply compensation at both radiofrequency (RF) excitation and receiving (i.e. echo train). Specifically, the CF offsets are applied at the RF excitation to reduce signal loss especially when spectral spatial water excitation pulse is used. During the EPI echo train, gradient compensation is applied according to the eddy current calculation and CF compensation is applied according to both the eddy current and B0 offset calculations. The compensation during echo train is to reduce image distortion, which includes slice dependent shift. Distortion correction in image reconstruction is also applied to correct any residual HOEC [2].

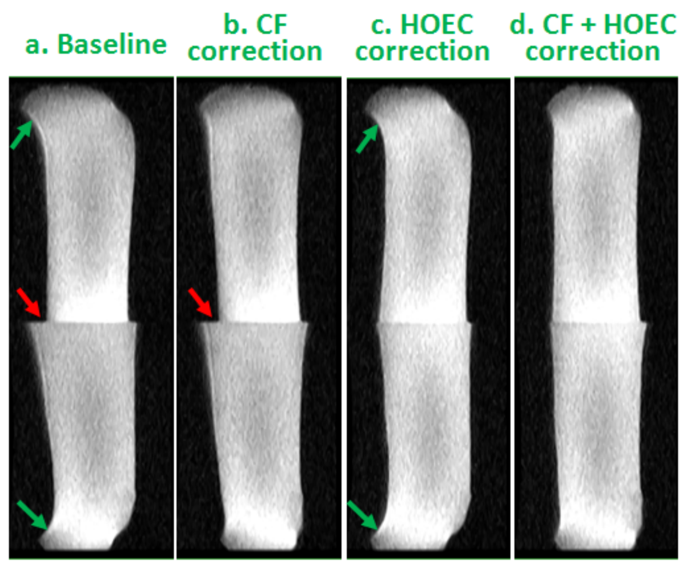

Fig. 1. Sagittally reformatted images from a two-station axial DW-EPI scan with a rectangular cuboid phantom. Phase encoding is in the horizontal direction. The image without either correction (baseline) has a large discontinuity at the station boundary (red arrow) and curved sides especially near phantom ends (green arrows). The image with the combined CF and HOEC correction shows significantly reduced discontinuity and curvature on the sides. See text in the RESULTS section for more details.

RESULTS

Two-station axial spin-echo DW-EPI images on a phantom were collected on a 3T GE scanner using the whole body coil for RF transmission and receiving. The phantom was a 60-cm-long, 10-cm-diameter cylinder. The remaining parameters were: S/I coverage per station = 30 cm, slice thickness = 1 cm, matrix size = 128× 128. Images with diffusion directions on X, Y, and Z axes were all collected, but only the Y diffusion weighted images (sagittally reformatted) are shown for limited space. Shown in Fig. 1 are images without either CF or HOEC correction (baseline, Fig. 1a), with CF correction only (Fig. 1b), with HOEC correction only (Fig. 1c), and with both corrections (Fig. 1d). The horizontal direction is the phase encoding axis and the vertical direction is the slice axis. The baseline has curved boundaries on the sides as well as near the ends of the phantom (marked by the green arrows) primarily due to the slice dependent B0 offsets. There is a large geometric discontinuity at the station boundary (marked by the red arrow) due to a large quasi-linear eddy current in the phase encoding direction (which causes an FOV change). The CF correction makes the sides of image straighter but still tilted; the geometric discontinuity and the associated slight curvature on the sides are still apparent as well. HOEC correction minimizes the geometric discontinuity, but the slightly tilted sides and large curvatures near phantom ends still exist. With both corrections, the boundary discontinuity and curvatures on the phantom sides are simultaneously minimized.

CONCLUSIONS

The proposed combined CF and HOEC correction has been shown effective in correcting B0 and eddy current induced image distortions. This correction does not require protocol-dependent reference scan (HOEC correction only needs a one-time, per-system calibration) and therefore is advantageous from a workflow standpoint. The method applies to DW-EPI imaging in general, and can be particularly useful in reducing the boundary discontinuities in multistation whole body DW imaging.

REFERENCES

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