k-space Correction of Eddy Current-Induced Distortions in DW EPI

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Introduction

Eddy-currents (ec) induced by diffusion weighted (DW) gradient pulses distort DW echo-planar images (EPI) [1]. Although the effect of ec's may be minimised prior to data acquisition, this requires hardware which often may not available in an MRI scanner [2-3]. Correction methods working in the image domain [1] often only partially correct the distortions (for example, they cannot correct for the temporal variation of the ec's during data acquisition). More complete ec corrections can be performed by measuring the ec field in the time domain; however they require additional reference scans for each DW acquisition [4]. This work describes a time-domain ec correction method without these limitations.

Method

First, phase evolutions of reference ec fields are measured as in [2]. Temporal parameters (eg, DW gradient duration, length of EPI acquisition), identical to those of DW-EPI protocols are used. DW gradient vectors parallel to the physical gradient axes (*x,y,z*) and with the maximum usable strength G_m are used. For each DW vector, 4 ec terms are measured: the spatially-invariant (B_{0e}) and the 3 linear terms along *x,y,z*. Secondly, for any arbitrary DW gradient vector, the 4 ec terms arising from the component of the vector along any physical gradient axis are calculated by linearly scaling the respective reference ec evolutions by the value of the component relative to the gradient maximum. Adding the homologous ec terms (for example the B_{0e} term) generated by the 3 DW gradient components together yields the final 4 ec phase evolution terms due to the arbitrary DW gradient. Thirdly, these 4 terms are used in image reconstruction. The *x,y,z* linear ec terms are transformed to *read,phase,slice* terms. For a given slice position, the spatially-invariant ec term is calculated using the B_{0e} and *slice* ec terms, and the resultant ec phase evolution is subtracted from the phase of the raw data of the respective slice on a point by point basis. The phase evolutions of the *read* and *phase* ec field are added directly to the k-space coordinates of the ideal (rectilinear) k-space trajectory. Data gridding using a Kaiser-Bessel window is applied for image reconstruction [5].

Experiments

The method was implemented in a 3T wholebody magnet (Magnex, id=16cm), equipped with a self-shielded gradient set (Magnex, id=10cm, max strength per axis 10kHz/mm) and an MRRS console. The system has no digital preemphasis, and the settings supplied by the manufacturer were used. A uniform spherical phantom of silicone oil (id=2cm) was used due to its small diffusion coefficient. Duration and separation of DW gradients were 5 and 22 ms, respectively, resulting to a b-value of 1654s/mm^2, for G_m=9kHz/mm. Ec measurement used 7 2mm-thick slices (gap 1mm). A 64x64 EPI data matrix was considered with 2.5μs dwell time. Since a gradient ramp time of 100μs was used, total duration of EPI acquisition window was (200+64*2.5)*64/1000=23ms. DW-EPI was performed on transverse slices with 5cm FOV, using the same parameters as the ec protocol. 18 uniformly arranged DW gradient directions were acquired.

Results & Discussion

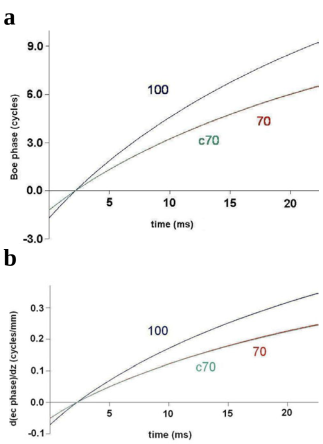

Figure 1

Figure 1 plots phase evolutions of the ec field due to *z* DW gradient. (a) shows the term due to B_{0e} ec is expressed in cycles (=rad/2π), (b) shows the *z* linear term expressed in cycles/mm. The plots labelled *100* and *70* correspond to **measured** phase evolutions caused by G_m and 70% of G_m respectively, while the plots labelled *c70* refer to phase evolutions **calculated** as 70% of the respective *100* plots. The close agreement between *70* and *c70* plots demonstrates that ec reference measurements are required only for G_m and not for every individual DW gradient value used by the DW protocol. Thus the method can be also applied for DW protocols using a large number of DW gradient values and/or directions (for example for diffusion tensor measurements).

Figure 2 shows images from a slice at -6mm distance from the magnet isocentre: (a) a baseline EPI (without DW), and (b-d) the standard deviation (SD) of all the DW acquisitions with: (b) no ec correction, (c) correction of the B_{0e} term only and (d) full k-space correction (images b-d have identical intensity scaling). Ec distortions cause a hyperintense halo around the edge of the phantom. The distortions are prominent after correcting only for the B_{0e} term, and are clearly reduced after the full implementation of the corrections.

a b c d

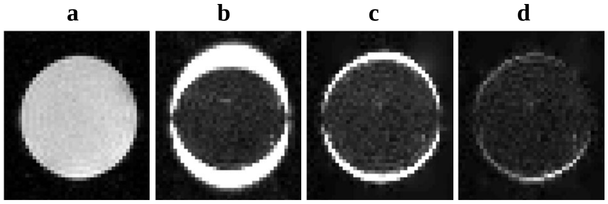

Figure 2

Conclusions

A method for correction of ec induced distortions of DW-EPI data has been described. It estimates the ec field, and corrects the k-space data. The method requires a small number of reference scans, which are not specific to individual acquisitions of a given DW protocol, and may be performed as part of a regular quality assurance (QA) procedure, since variation of the measurements over time may indicate hardware instability.

References [1] Haselgrove JC et al, *Magn Reson Med* 36: 960-964 1996 [2] Papadakis NG et al, *Magn Reson Med* 44: 616-624 2000 [3] Zhou XJ et al, *Proc 7th ISMRM* 1818 1999 [4] Jezzard P et al, *Magn Reson Med* 39: 801-812 1998 [5] Jackson JI et al, *IEEE Trans Med Imaging* 10: 473-478 1991

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