Ghost Reduction for Oblique EPI using Entropy Based Compensation of Phase Encoding Blips

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INTRODUCTION

System time delays resulting in phase offsets make oblique imaging with EPI a challenge due to ghosting. Different methods have been tested to compensate for this delay, which cause shifts in both phase- and frequency encoding directions. It has been shown that compensation blips for phase encoding can reduce ghosting artifacts (1). Also, a fast method for reducing shifts in the frequency encoding direction, and thereby limit ghosting, is presented in (2).

In this study a new sequence has been developed to be used as a calibration scan with an altering compensation blip factor for phase encoding, followed by an entropy calculation to find the best compensation blip factor ξ. This method can be used both with single and multi-shot EPI sequences with equally good ghost reduction. Using this calibration scan for each scan plane angle in the exam is a robust technique that results in a major improvement of ghosting artifact suppression for oblique EPI scans. The presented method has great potential when implemented in oblique EPI such as fMRI, DWI, PWI and cardiac imaging.

METHOD

Acquiring oblique EPI images induces significant system time delays, which cause misregistrations in k-space, both in the frequency- and phase encoding directions. Correction for artifacts caused by frequency encoding errors is handled with a realignment of frequency encoding lines in k-space (2). Remaining ghosting artifacts are mainly due to phase encoding misregistrations in k-space, i.e. an offset between the phase encoding lines in k-space. If lines are not equidistant in the phase encoding direction the offset will be interpreted as a ghost in image-space. To get a robust solution, independent of patient/subject and angle of scan plane, a calibration scan sequence has been developed. The sequence alters the phase encoding blips with a compensation blip (1) factor ξ. This procedure is executed for a range of ξ, and for each ξ_i a k-space is produced. Every k-space is then adjusted for misregistrations in frequency encoding direction (2) and an entropy calculation (3) is performed. The ξ_i corresponding to the image with the lowest entropy is used to compensate the phase blips in the following oblique EPI sequence. The calibration scan is expected to add 20-30 seconds of scan time to the exam using 10-15 compensation blip factors in the range of [-1 1].

RESULTS

A total of 18 scan sessions were performed on a 1.5 T clinical MRI scanner (Signa Excite; GE Medical Systems, Waukesha, WI, USA) to verify the presented method, twelve phantom scans and three scans with human subjects. Each scan included four calibration series with 128 steps over a compensation blip factor range of [-2 2]. The first two series were single shot EPI with 64 x 64 matrixes, one axial, and the other tilted 45 degrees in the xy-plane. The following two series were three shot EPI sequences, with 128 x 128 matrix and the same scan planes as the first two series. For each series the entropy value was calculated for the 128 different ξ_i as plotted in figure 1 for three different series. Also shown here is the uncompensated image acquired with $\xi = 0$, and the compensated image resulting from the ξ corresponding to the lowest entropy value. As can be seen from figure 1 b and c, corresponding to the oblique scan planes, there is a significant reduction of ghosting artifacts in the compensated images compared to the uncompensated images.

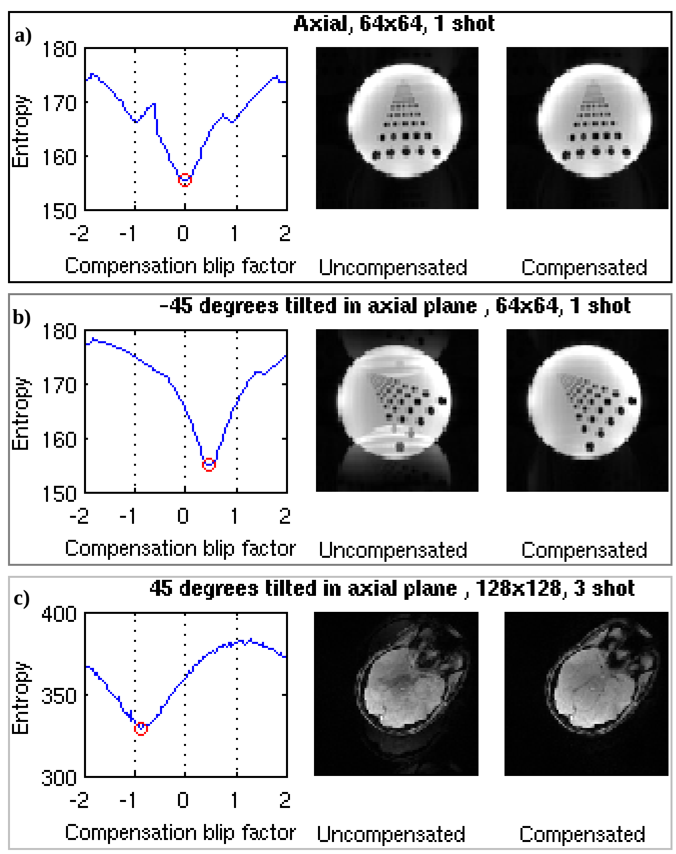

Figure 1 a,b,c: Left: Image entropy for ξ = [-2 2]. Middle: Uncompensated image. Right: Compensated image with ξ corresponding to the lowest entropy.

DISCUSSION

The sequence developed shows good results and has significant potential for use in conjunction with EPI scans with high temporal resolution demands and oblique scan planes. Such scans include DWI, PWI and fMRI. The propeller EPI technique would also benefit from the use of entropy based compensation of phase encoding blips, in particular the SAP-EPI (4).

REFERENCES

1. Reeder SB, Atalar E, Faranesh AZ, McVeigh ER. Referenceless Interleaved Echo-Planar Imaging. Magn Reson Med 1999; 41:87-94.
2. Nordell A, Bammer R, Skare S. Major Speed-Up of Nyquist Ghost Correction in ramp-sampled EPI. In Proceedings of the Joint Annual Meeting ISMRM-ESMRMB, Berlin, Germany, 2007. p. 367.
3. Clare S. Iterative Nyquist Ghost Correction for Single and Multi-shot EPI using Entropy Measure. In Proceedings of the 11th Annual Meeting of ISMRM, Toronto, Ontario, Canada, 2003. p. 1041.
4. Skare S, Newbould RD, Clayton DB, Bammer R. Propeller EPI in the other direction. Magn Reson Med 2006; 55(6):1298-1307.