N/2 ghosting artifacts in a radial 3D EPI pulse sequence
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INTRODUCTION: Echo-planar imaging (EPI)-based techniques are susceptible to modulations in phase between alternating echoes, leading to the well-known N/2 ghosting artifact.1 Phase differences between alternating echoes are typically corrected using phase correction scans, which acquire reference echoes with phase encoding gradients turned off. We characterize and introduce a phase correction scheme for this artifact in 3D RAZIR,2 a new radial 3D GRE-EPI pulse sequence.

METHODS: Sequence design: 3D RAZIR uses in-plane radial sampling and through-plane Cartesian sampling to produce a cylindrical 3D $k$-space (Fig. 1). The use of through-plane ($k_z$) blip phase encoding causes an N/2 ghosting artifact to distort both the coronal (x-z) and sagittal (y-z) views of the 3D volume, and the use of a radial $k$-space trajectory causes the phase to change between acquired radial views.3 In other words, phase errors propagate both within a 3D echo train and between 3D echo trains acquired at different radial views, leading to a “radial 3D N/2 ghosting” artifact. We developed a real-time phase correction scheme that uses internal reference lines4 to acquire reference echoes at each radial view. Within each TR (Fig. 1), four reference echoes are acquired with the same in-plane radial angle as the phase encoded echo train. A prephasing gradient is played after the last reference echo is acquired, and the phase encoded echo train is acquired.

Subjects: One healthy volunteer was recruited with IRB approval.
Image acquisition: In vivo images were acquired using 3D RAZIR with a 3.0 T MR scanner (Tim Trio, Siemens AG, Erlangen, Germany). Scan parameters: TE/TR = 36/81 ms, readout bandwidth = 1502 Hz/px, echo train length = 76, flip angle = 45°, slices = 76, matrix size = 128 × 128 × 76, voxel size = 1.7 × 1.7 × 1.7 mm3.
Phase correction: In the image domain, the two forward echoes were averaged and the two reverse reference echoes were averaged5 for each radial view. The difference in phase angle of the forward and reverse echo was computed for each radial view and fit using polynomial regression to compute a radial view-dependent slope ($\phi_1$) and intercept ($\phi_2$). With knowledge of the phase differences due to $\phi_1$ and $\phi_2$ for each radial view, a spatially-dependent phase shift1 is applied to the forward and reverse phase encoded echoes to correct for N/2 ghosting.

RESULTS AND CONCLUSIONS: Figure 2 illustrates the dependence of $\phi_1$ and $\phi_2$ on radial view, indicating how phase modulations between alternating echoes in radial 3D EPI vary by radial view. Figure 3 demonstrates the success of our phase correction scheme before (top) and after (bottom) the algorithm was applied in coronal, sagittal, and axial planes. The N/2 ghosting artifact is visible in the partition direction of the coronal (x-z) and sagittal (y-z) planes where $k_z$ phase encoding occurs. Phase modulations that occur in radial 3D multiecho acquisitions like 3D RAZIR can be corrected with our technique. Our phase correction scheme obviates the need for a separate reference scan.