N/2 ghosting artifacts in a radial 3D EPI pulse sequence

Sumeeth Vijay Jonathan[1], Parmede Vakil[1], Yong Jeong[1], and Timothy Carroll[1,2]
[1]*Biomedical Engineering, Northwestern University, Chicago, IL, United States*, [2]*Radiology, Northwestern University, Chicago, IL, United States*

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 lines[4] 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.

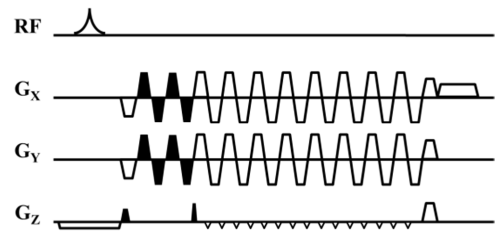


FIG 1. Each TR samples a cylindrical 3D *k*-space and acquires reference echoes (shaded) with the same in-plane radial angle as the phase encoded echoes.

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 mm^3.
Phase correction: In the image domain, the two forward echoes were averaged and the two reverse reference echoes were averaged[5] 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 (ϕ_1) and intercept (ϕ_2). With knowledge of the phase differences due to ϕ_1 and ϕ_2 for each radial view, a spatially-dependent phase shift[1] 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 ϕ_1 and ϕ_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.

FIG 2. ϕ_1 and ϕ_2 vary by radial view. Phase modulations in radial 3D EPI are radial-view dependent.

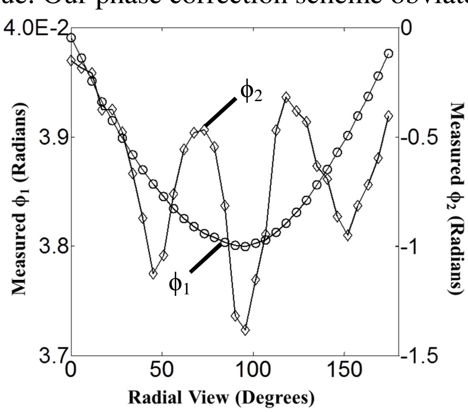
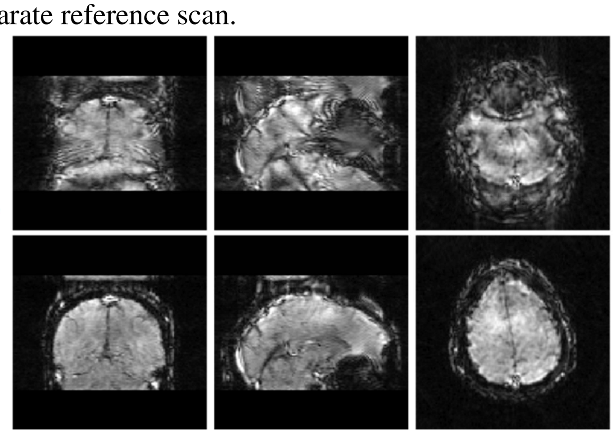


FIG 3. N/2 ghosting before (top) and after (bottom) phase correction. Our algorithm reduces N/2 ghosting in radial 3D EPI.



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