Simultaneous echo refocused (SIR) EPI with constant TE

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Introduction:
Simultaneous echo refocused (SIR) EPI has greatly accelerated the acquisition of both fMRI and DTI data sets (1,2). However, the effective echo time (TE) of each individual SIR slice can differ by several milliseconds, resulting in slice dependent signal intensity and BOLD contrast. Here, we propose a constant TE (cte) version of the SIR method that is able to use TR specific phase correction navigators while maintaining the minimum TE and TR of the original SIR method.

Methods:
SIR2 (SIR with acceleration factor 2) with constant TE was implemented by introducing a negative PE gradient pulse (PE blip) in between the two SIR excitations (Fig 1). This shifts the 1st SIR echo earlier in time to match the TE of the 2nd SIR slice. However, introduction of the PE blip, invalidates the phase correction navigator of the 1st SIR slice by imposing a phase shift on the navigator signal. To remedy this, we added a positive and negative PE blip before and after the phase correction navigators to obtain zero net phase shift in the even TRs only (Fig 1). This implementation of SIR with constant TE generates navigators for the 1st SIR slices in even TRs and navigators for the 2nd SIR slices in odd TRs. Combining pairs of adjacent TRs enable TR specific phase correction of all slices (3).

SIR2 with and without constant TE were acquired on a Siemens 3T Magnetom Trio in both a spherical water phantom and a 27 year old healthy male. Scan parameters were TR = 600ms, TE = 40ms (1st SIR slice) 35ms (2nd SIR slice), slice thickness = 3mm, number of slices = 36, number of concatenations = 3, FOV = 240 x 240 mm^2, matrix size = 80x80, flip angle = 50 deg, partial Fourier = 7/8. On the human subject, BOLD responses were evoked using an 8Hz flashing checkerboard block design paradigm. Three 1.5 min runs of the paradigm were collected for each SIR with and without constant TE. Student's t-values were calculated for these two conditions separately.

Results:
Phantom study: SIR2 without constant TE resulted in lower intensity odd slices relative to even slices (Fig 2A). This is expected given the TE for odd slices was 5 ms longer than that of even slices. The SIR slice intensity difference, for the given scan protocol, was quantified to be ~2% of the signal intensity at TE = 35ms (Fig 2B). SIR2 with constant TE eliminates this artifactual across slice intensity variation.
Human study: SIR2 without constant TE resulted in a longer TE for odd slices and correspondingly significantly higher t-values (stronger BOLD signal changes) relative to even slices (Fig 2C, $p < 0.001$, paired regression line slope t-test). The increase in t-value, is quantified to be 19% (ratio of regression line slopes for even vs odd slices). SIR2 with constant TE reduces this artifactual difference in BOLD signal across SIR slices.

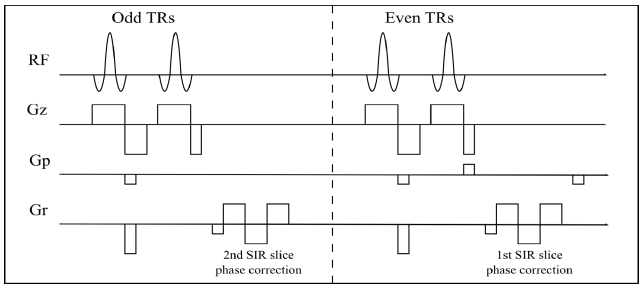

Figure 1. SIR with constant TE pulse sequence diagram.

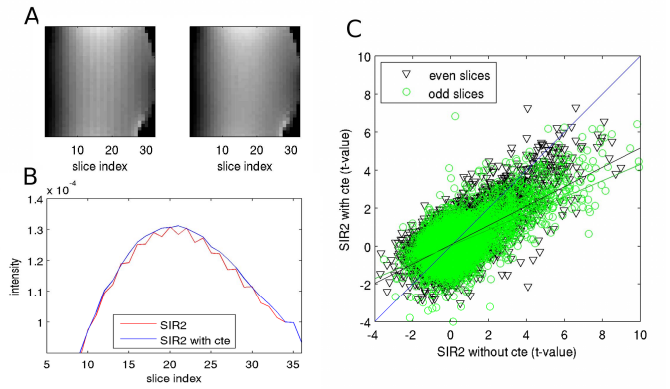

Figure 2. A) Left: phantom cross section without constant TE. Right: phantom cross section with constant TE. B) Intensity line plot across phantom cross section. C) Scatter plot of t-values comparing SIR2 with and without constant TE (cte). Voxels from even slices are plotted as black triangles. Voxels from odd slices are plotted as green circles. Best fit linear regression lines are plotted for even and odd slices separately in corresponding colors.

Conclusion:
SIR with constant TE eliminates intensity and BOLD contrast differences across SIR slices that may otherwise complicate statistical analysis. Though only shown here for SIR2, the technique is extendable to higher SIR accelerations as well.

References:
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