**AN EFFECTIVE METHOD TO INCREASE TEMPORAL OR SPATIAL RESOLUTION IN INTERLEAVED ECHO PLANAR IMAGING**

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**INTRODUCTION:** Interleaved echo planar imaging (EPI) offers increased SNR over single-shot EPI, but suffers from ghosting in the phase encode (PE) direction due to abrupt phase modulations along the center of k-space [1]. A common solution is to employ echo time shifting (ETS) [2-3]. Although ETS corrects for ghosting in a robust, non-iterative, and automatic manner, it does so at the expense of increasing total scan time [5]. There is also a penalty in scan efficiency since the A/D time-to-TR ratio is low. In this work, a simple, yet effective scheme to increase the efficiency of ETS is proposed. Using the proposed technique, shorter scan times are achieved in interleaved EPI acquisitions. Alternatively, the proposed scheme can acquire higher resolution images when total scan time is fixed.

**METHODS:** In conventional ETS, pre-wait idle time $T_{PR}$ and post-wait idle time $T_{PO}$ are added before and after the echo train, respectively [2]. Time $T_{PO}$ is incremented by some value $\Delta$ at each excitation, while $T_{PR}$ is decremented by the same amount [5]. The proposed scheme replaces each of these idle times with an extra readout when either duration is greater than the gradient switching time $T_{SWITCH}$. When this condition is met, there is sufficient time to switch the gradients and play out an A/D window. The steps of the proposed scheme are summarized in Table I, and illustrated in Fig. 1 for the case of flyback EPI.

The A/D time of the new readout is less than a full echo (Table I, Step 2). This duration changes with each excitation—shrinking by $\Delta$ in post-wait replacement, while growing by $\Delta$ in pre-wait replacement. Hence, sequence TR is not affected, and a series of partial echoes is acquired at higher $k_x$ spatial frequencies. The linear change in the partial echo A/D time results in a parallelogram coverage of k-space (Fig. 1c).

Since more data at higher $k_x$ spatial frequencies are collected within one TR as compared to conventional ETS, fewer excitations are required for a given spatial resolution in the PE direction. Alternately, the total number of excitations can be fixed. In this case, more k-space lines that cross the $k_x$ axis are acquired in the same total scan time. The improvement in scan time or PE resolution depends on the interplay between $T_{PR}$, $T_{PO}$, and $T_{SWITCH}$, which in turn relies on echo train length (ETL) and readout bandwidth (BW) [5].

Experiments were performed on a 1.5 T GE Excite scanner (40 mT/m gradient strength with 150 mT/m/ms slew rate) using a 2D gradient recalled echo sequence combined with an interleaved flyback EPI trajectory. A GE resolution phantom was first scanned to demonstrate resolution gain for a fixed scan time. BWs investigated were 15.625, 31.25, 62.5, 83.3, and 125 kHz; while ETL = 2, 4, 8. Two scans were performed for each (BW, ETL) pair: one with conventional ETS, and another using the proposed scheme. Imaging parameters were: $TE/TR = 15/37$ ms, slice thickness $= 3$ mm, $FOV = 19.2 \times 19.2$ cm$^2$, flip angle $= 30^\circ$, number of excitations $= 32$ (total scan time 1.2 s). The number of $k_x$-space lines that crossed the $k_x$ axis was then compared. In vivo images of the brain of a healthy volunteer were acquired with an 8-channel head coil to demonstrate the reduction in total scan time when the target in-plane resolution is fixed. Here, in-plane resolution $= 0.75 \times 0.75$ mm$^2$, $TE/TR = 11/37$ ms, and $(BW, ETL) = (62.5$ kHz, 4). All other imaging parameters were kept constant. Excitations proceeded until the required extent in $k_x$ was covered.

**RESULTS & DISCUSSION:** Figure 2 shows the improvement in resolution expressed as a percentage for various (BW, ETL) pairs. Improvements are significant when shorter ETL and lower BW are used. For the case of ETL = 4 and 8, the gain in PE resolution is approximately linear over a wide range of BWs. At moderate BWs, improvements of between 5% and 25% are possible. For example, when $(BW, ETL) = (62.5$ kHz, 4), 144 lines cross the $k_x$-space lines that crossed the $k_x$ axis was then compared. In vivo images of the brain of a healthy volunteer were acquired with an 8-channel head coil to demonstrate the reduction in total scan time when the target in-plane resolution is fixed. Here, in-plane resolution $= 0.75 \times 0.75$ mm$^2$, $TE/TR = 11/37$ ms, and $(BW, ETL) = (62.5$ kHz, 4). All other imaging parameters were kept constant. Excitations proceeded until the required extent in $k_x$ was covered.

**CONCLUSION:** This work demonstrates the possibility of shortening scan times, or improving spatial resolution in interleaved EPI acquisitions. The proposed method shows great promise in rapid imaging schemes such as functional and cardiac imaging where temporal and spatial resolution are important.

**REFERENCES:**


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