Improvents in Single Shot Z-shim Using Parallel Imaging

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Introduction: Susceptibility artifacts are common in MRI, due to discontinuities in magnetic properties between bone, air and soft tissue. The resulting artifact manifests as either signal loss and/or distortion in the MR image. The effect is amplified in T2* weighted techniques such as fMRI, where long TE gradient echo imaging is performed. Signal loss can be reduced in the affected regions by playing a small slice gradient prior to readout. This gradient, often called "z-shim", acts to restore signal from the susceptibility region [1]. The combination of z-shimmed image with a second image, acquired without gradient compensation, creates a composite image that exhibits reduced signal loss. An inherent problem in multi-shot z-shim techniques is that the scan time increases proportionally with the number of shots. To avoid this limitation, several single shot pulse sequences have been developed, including those based on an interleaved EPI readout train[2,3] and those that use multi-echo pulse trains[4,5]. Interleaved techniques compensate for the signal loss, yet increases geometric distortion because of the doubling of the readout window. Multi-echo techniques, while less sensitive to geometric distortion, because of intact readout window length, result in acquired images with less than optimal contrast, due to inherent differences in echo times. Both families of techniques should be improved by incorporation of phased array parallel imaging. Techniques such as GRAPPA [6] and SENSE [7] effectively reduce the necessary readout window for EPI. In the case of interleaved single-shot z-shim [2,3], the readout window doubling can be compensated by a rate 2 reduction using parallel imaging. For multi-echo z-shim, the readout window shortening results in smaller spatial distortion as well as less discrepancy in echo times. The latter case may be optimal since signal loss and image distortion can both be minimized in multi-echo z-shim techniques, such as ZSAGA [5]. This paper details the improvement of ZSAGA with parallel imaging using an eight-channel phased array coil at 3T.

Methods: Human studies were performed, with proper consent, using a Siemens 3 Tesla Trio scanner, equipped with an 8 channel phased array head coil, to assess the improvement parallel imaging can have on single shot z-shim EPI, and specifically the ZSAGA pulse sequence. The pulse sequence acquires two echoes within one TR. The first echo is a standard gradient echo EPI, while the second echo is an asymmetric spin echo. This scheme ensures that the two images will have the same echo time with respect to T2' weighting, which is important for BOLD contrast. The asymmetric spin echo portion of the sequence includes a slice specific z-shim setting for recovery of susceptibility losses. The final image is a composite formed by the square root of sum of squares. For comparison, two experiments were performed, a standard ZSAGA acquisition and a combined GRAPPA-ZSAGA acquisition with a reduction factor of 2. GRAPPA fitting to missing k-space lines is performed using six pre-scan calibration lines and a block size of 4. The data is acquired on five 5-mm thick slices on a normal human volunteer. The slices are positioned axially near the level of the ACPC. The z-shim is calibrated online for signal recovery in the inferior frontal area using manual adjustment. Sequence parameters include a TR/TE of 1000/35 ms, a 220 mm FOV, a matrix size of 64×64 (64×32 for GRAPPA), and an EPI readout window of 60ms (30ms for GRAPPA).

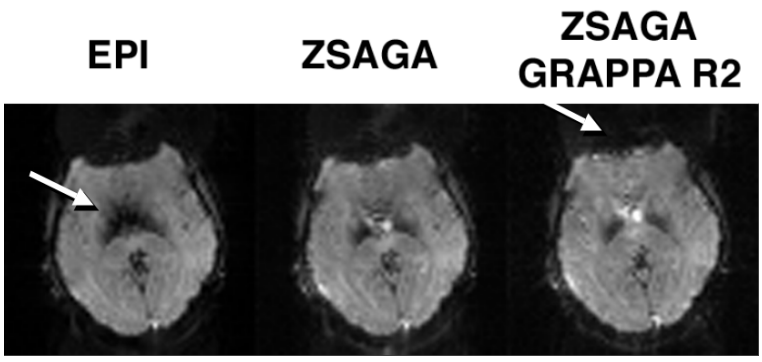

Figure 1. This image panel shows the same slice from an EPI (left), ZSAGA(center), and ZSAGA reconstructed with GRAPPA (right). The arrow on the left indicates the region of susceptibility loss recovered in the ZSAGA image, while the right arrow indicates a region of reduced image distortion. The reduction in image distortion is due the shorter readout period in parallel imaging.

Results and Discussion: Fig. 1 displays images of one of the 5 slices from the above experiment. The left image is reconstructed from the standard gradient echo EPI portion of the ZSAGA data. There is a large area of signal loss indicated by the arrow. The center image is the composite image resulting from the complete ZSAGA acquisition. While a significant portion of the signal loss has been recovered, an area of image distortion remains in the frontal area. The right image is the ZSAGA composite using GRAPPA reconstruction. In this image the EPI readout period was reduced from 60 ms to 30 ms using parallel imaging. The reduced image distortion is indicated by the arrow. The result indicates a significant improvement for single shot z-shim techniques. An added benefit to multi-echo z-shim sequences is more uniform contrast in the composite image.

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