# Field-corrected 3D multiecho gradient echo: Simultaneous extraction of quantitative R2*, T2* weighting, SWI, and venography

**R. M. Lebel[1], and A. W. Wilman[1]**
[1]Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada

## Introduction

Susceptibility-weighted imaging (SWI) **[1]** exploits subtle phase evolution in gradient echo (GRE) data to sensitize images to susceptibility shifts. It is particularly promising for neurological studies at high magnetic field strengths since short echo times, which maintain high signal levels, yield sufficient phase evolution for contrast enhancement. Recently, combined angiography and susceptibility-enhanced venography was demonstrated using a 3D multiecho GRE acquisition **[2]**. As presented, this technique yielded low tissue contrast making it ill suited for anatomical imaging. Subsequently, two articles demonstrated an intensity correction algorithm for reduction of background gradient artifacts, optimized combination of echoes for producing artifact suppressed, high contrast-to-noise images **[3]**, and quantitative $R_2$* mapping using the corrected images **[4]**. These works were restricted to 2D acquisitions and failed to demonstrate SWI, venography, or full brain coverage. To date, no work has fully exploited the information available in 3D multiecho images.

We employ multiecho 3D GRE, with an additional rapid pre-scan to minimize diverging phase ramps in the readout direction, with advanced post-processing techniques to correct for macroscopic field gradients. Furthermore, we employ the field correction information to improve phase map generation during SWI processing – a novel use of this information. Ultimately this technique yields the following low-artifact, high-resolution data sets: (1) $T_2$*-weighted images, (2) quantitative $R_2$* maps, (3) SWI, and (4) venography mIPs.
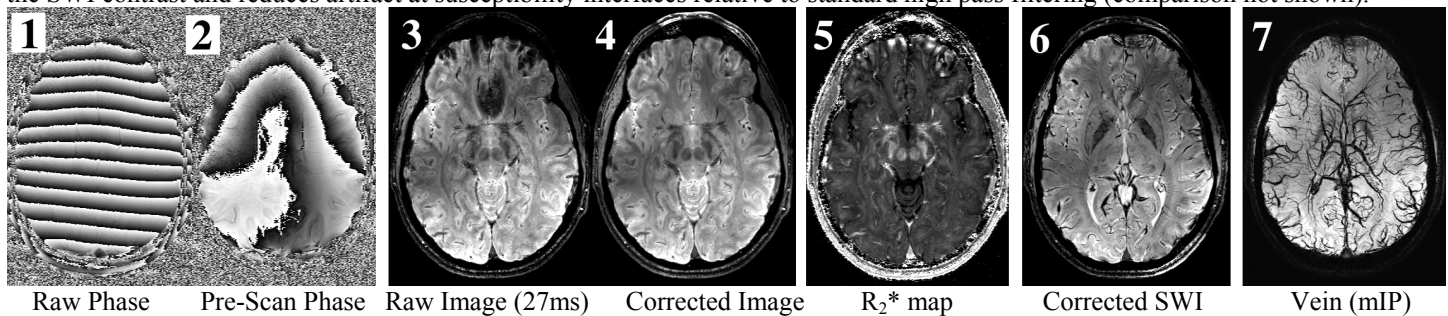
## Methods

A 3D multiecho GRE sequence with monopolar readout was implemented on a 4.7 T Varian scanner. A 3.0 second pre-scan, sampling central k-space lines, permitted scaling of flyback lobes to align echoes and readout windows. Repetition time was 48 ms, tip angle was 8°, and seven echoes, starting at 3.8 ms and spaced by 5.9 ms, were collected. The field-of-view was 256 x 180 x 180 mm$^3$ with a matrix size of 512 x 240 x 90 pixels (resolution of 0.50 x 0.75 x 2.0 mm$^3$). This, and similar protocols, have been tested on over 10 healthy volunteers; typical results are presented.

Frequency maps were obtained by temporally fitting the phase evolution; spatial unwrapping was then performed with PHUN **[5]**. Low pass filtering with a 5 mm Gaussian kernel isolated background frequency gradients; intensity correction factors for repairing susceptibility-induced signal loss and composite (intelligently summed over all echo times) $T_2$* weighted images were computed according to **[3]**. Quantitative $R_2$* maps were obtained by weighted non-linear least squares fitting of the intensity corrected images. Phase maps for SWI were obtained via weighted average of filtered phase images from all echo times; weighting factors were computed for optimal contrast (increases with TE), and minimal background artifact.

## Results

Figs 1 and 2 show raw phase maps without and with pre-scan optimization. Reduced phase wrap following pre-scan permits accurate frequency calculation and reduced filter burden during SWI processing. An uncorrected image at TE=27 ms is shown in Fig 3. Field correction and optimal image combination effectively remove major susceptibility artifacts, Fig 4. An $R_2$* map, using corrected images is shown in Fig 5, scaled from 0 to 100 s$^{-1}$; accurate rates in frontal brain regions are only obtained with our method (comparison not shown in abstract). SWI and vein-enhancing mIPs are shown in Figs 6 and 7. Field correction information improves the SWI contrast and reduces artifact at susceptibility interfaces relative to standard high pass filtering (comparison not shown).



| Raw Phase | Pre-Scan Phase | Raw Image (27ms) | Corrected Image | $R_2$* map | Corrected SWI | Vein (mIP) |
|---|---|---|---|---|---|---|

## Conclusion

Multiecho 3D GRE can be exploited to create numerous distinct data sets. A rapid pre-scan to center echoes improves data quality and eases SWI phase filtering. We demonstrate, for the first time, high-resolution artifact-reduced $T_2$*-weighted images, accurate $R_2$* quantification, SWI, and venography of the whole brain at high field strength.

**References**: **[1]** Haacke. (2004). MRM, 52(3), 612-8. **[2]** Du. (2009). JMRI, 30(2), 449-54. **[3]** Volz. (2009). Neuroimage, 45(4), 1135-43. **[4]** Baudrexel. (2009). Magn Reson Med, 62(1), 263-8. **[5]** Witoszynskyj. (2009). Med Image Anal, 13(2), 257-68.