Temporal phase correction of quantitative T_2 data

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Introduction: Typical MR images are formed by taking the magnitude of reconstructed complex values. The magnitude operation changes the noise distribution from Gaussian to Rician [1], and can artificially inflate the intensity of the final T_2 time in T_2 distributions calculated using non-negative least squares (NNLS) algorithms. NNLS is used to fit a summation of exponential decays to data acquired using multiecho imaging techniques. The artifacts caused by non-Gaussian noise distributions are becoming more relevant as scientists begin to identify tissue compartments with small intensity long T_2 decays [2,3]. Phase can be related to physiological changes in the subject during scan-time, as well as edges within the field of view, both of which can have deleterious effects on phase correction algorithms that work spatially across a single image. Here we propose, and examine, a phase correction technique that considers the phase temporally instead of spatially across the image, allowing the calculation of T_2 distributions by fitting a sum of exponentials to echo-train phase-corrected real-valued multiecho data.

Methods: Data were acquired on a 9.4 T Bruker Avance MR system using a single slice, 3 ms spaced 128 multiecho spin-echo sequence through a region containing the hippocampus and the corpus callosum in 5 healthy rats. Data were analyzed without and with temporal phase correction. Temporal phase correction was performed for pixels within tissue; a 5th order polynomial was fit through the phase of the echo-train in the original complex data on a pixelwise basis. The polynomial fit was assumed to be the zero-phase line, as shown in Fig 1. The phase of the complex data was multiplied by the complex conjugate of the zero-phase line, shifting the phase so that it oscillated about zero without affecting the magnitude intensities. A region of interest (ROI) was drawn inside the corpus callosum to select signals for analysis. The T_2 basis times were logarithmically spaced from 4.5 to 768ms and T_2 distributions were created using a regularized NNLS algorithm with the smoothing constraint $1.01\chi^2_{min} \leq \chi^2 \leq 1.015\chi^2_{min}$ [4] for both the magnitude and phase-corrected complex data. The T_2 distributions were separated into 3 regions for further analysis. Region 1, 2, and 3 include T_2 times (ms) of $4.5 \leq T_2 \leq 20$, $20 < T_2 \leq 200$, and $200 < T_2 \leq 768$, respectively. The geometric mean T_2 (gmT_2) and the area beneath the peak were determined for each region. Analysis was conducted using AnalyzeNNLS [5], which was easily modified to handle complex data. Regional values were compared using a paired 2-tailed Student's T-test with $p<0.01$ considered significant.

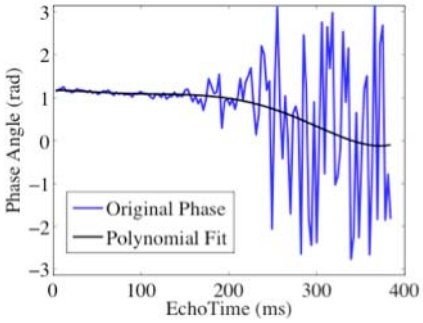

Fig 1: Original phase (blue) of multiecho complex data within a white matter pixel along with the polynomial fit (black).

Results: Phase correction, in addition to zeroing the bulk phase image, removed edge detail, as shown in Fig 2. The T_2 distributions were divided into 3 regions and the areas beneath the peaks, the gmT_2 times, and their standard errors (in brackets) are shown in the Table 1. The areas beneath the Region 2 peaks approached significance and the areas and gmT_2 times of the Region 3 peaks were significantly different.

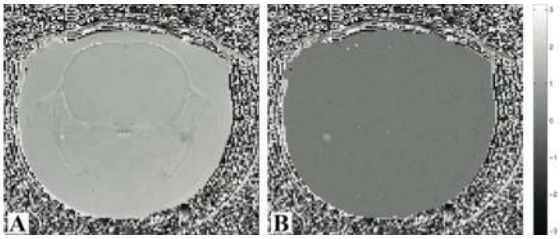

Fig 2: Phase images for the 10th echo before (A) and after (B) phase correction. Note how little detail remains after correction.

Discussion: Phase correction of complex multiecho data retains zero-mean Gaussian noise characteristics. Gaussian noise is an underlying assumption of the NNLS algorithm. Physiology, such as flow and edges, can drastically affect the phase of an image, and can interfere with the efficacy of phase correction methods based on spatial techniques. The phase correction method we propose considers the phase temporally on a pixelwise basis, resulting with a smooth phase map as shown in Fig 2B. Applying the echo-train phase correction technique resulted with significant changes in the area and gmT_2 of the Region 3 peaks, which could be relevant in pathology exhibiting low intensity longed T_2 times [2,3]. The differences in area of the Region 2 peak approached significance. We expected that the area of Region 3 would decrease, since altering Rician noise to Gaussian could remove a long T_2 time caused by the signal hitting the Rician noise-floor, which would result with an increase in the Region 1 and 2 peaks. We found no significant changes in the areas of Region 1 and 2 following temporal phase correction, although the Region 2 peak area approached significance. The area of the Region 3 peak did decrease significantly. Temporal phase correction of qT_2 data allows real-valued, Gaussian noise multiexponential decays to be analyzed, causing significant changes in the resulting T_2 distributions.

Region 1		Region 2		Region 3	
Area (%)	gmT_2 (ms)	Area (%)	gmT_2 (ms)	Area (%)	gmT_2 (ms)
3.8 (0.8)	5.8 (0.6)	95.1 (0.2)†	43.2 (0.6)	1.2 (0.2)‡	734 (9)‡
3.3 (0.7)	5.7 (0.4)	96.0 (0.6)†	43.3 (0.6)	0.7 (0.2)‡	704 (6)‡

Table 1: Peak areas and gmT_2. First top row contains magnitude data; bottom row is phase-corrected data. †$p<0.017$, ‡$p<0.01$ between original and phase-corrected data.

References: [1] Gudbjartsson & Patz. MRM 34:910-4 (1995). [2] Sirrs *et al*. Neuroradiology 242:236-43 (2007). [3] Laule *et al*. J Neurol 254:1479-87 (2007). [4] Whittall & MacKay. JMR 84:134-52 (1989). [5] www.imaginginformatics.ca/open-source/analyzennls.

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