Rician Noise and the T_2 Distribution: Fitting Complex Decays

T. A. Bjarnason[1], C. R. McCreary[2,3], J. F. Dunn[2,3], and J. R. Mitchell[3,4]

[1]Electrical and Computer Engineering, University of Calgary, Calgary, AB, Canada, [2]Experimental Imaging Centre, University of Calgary, Calgary, AB, Canada, [3]Radiology, University of Calgary, Calgary, AB, Canada, [4]Clinical Neurosciences, University of Calgary, Calgary, AB, Canada

Introduction: Magnetic resonance images are formed typically by taking the magnitude of reconstructed complex values. The magnitude operation changes the noise distribution from Gaussian to Rician [1]. This operation causes artifacts in T_2 distributions calculated using the non-negative least squares (NNLS) algorithm. This algorithm is used to fit exponential decays to data acquired using quantitative T_2 (qT_2) techniques. The artifacts caused by non-Gaussian noise distributions are becoming more relevant as scientists begin to identify tissue compartments with long T_2 decays [2,3]. Here we propose, and examine, one potential method to overcome this limitation: calculation of T_2 distributions using NNLS to fit phase-corrected complex data. Noise in the corrected complex data retains a zero-mean Gaussian distribution, and therefore meets a critical criterion of the NNLS algorithm.

Methods: Multi-echo acquisitions were performed on a 9.4 T Bruker Avance MR system using a 128 echo modified Carr-Purcell-Meiboom-Gill sequence with 3-lobe sinc pulses. A single slice was acquired (TR/TE = 1500/3 ms, 128×128, 4 averages, 1.5 mm thick) through a region containing the hippocampus and the corpus callosum in 5 healthy rats. The AC phase correction method [4] was applied to each echo, providing complex rephased data with Gaussian noise characteristics. A region of interest (ROI) was drawn inside the corpus callosum to select signals for analysis. A regularized NNLS algorithm with the smoothing constraint $1.01\chi^2_{min} \le \chi^2 \le 1.015\chi^2_{min}$ [5] was used to analyze both the magnitude and phase corrected complex data inside the ROI. The T_2 distributions were separated into 3 regions for further analysis, as depicted in Fig 2B. The geometric mean T_2 (gmT_2) and the area beneath the peak were determined for each region. Regional values were compared using a 2-tailed Student's T-test.

Results:

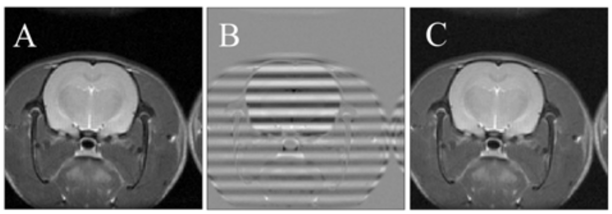

Figure 1: The magnitude (A) and the real component of the complex image before (B) and after (C) phase correction.

Region 1		Region 2	
Area (%)	gmT_2 (ms)	Area (%)	gmT_2 (ms)
8.6 (5.1)	7.1 (2.8)	90.1 (5.3)	42.8 (1.4)
9.8 (5.6)	7.2 (2.9)	90.2 (5.6)	44.15 (0.64)

Region 3	
Area (%)	gmT_2 (ms)
1.25 (0.59)	768 (na)
0.09 (0.10)	768 (na)

Table 1: Peak areas and gmT_2. First row contains magnitude data; second row is phase corrected data.

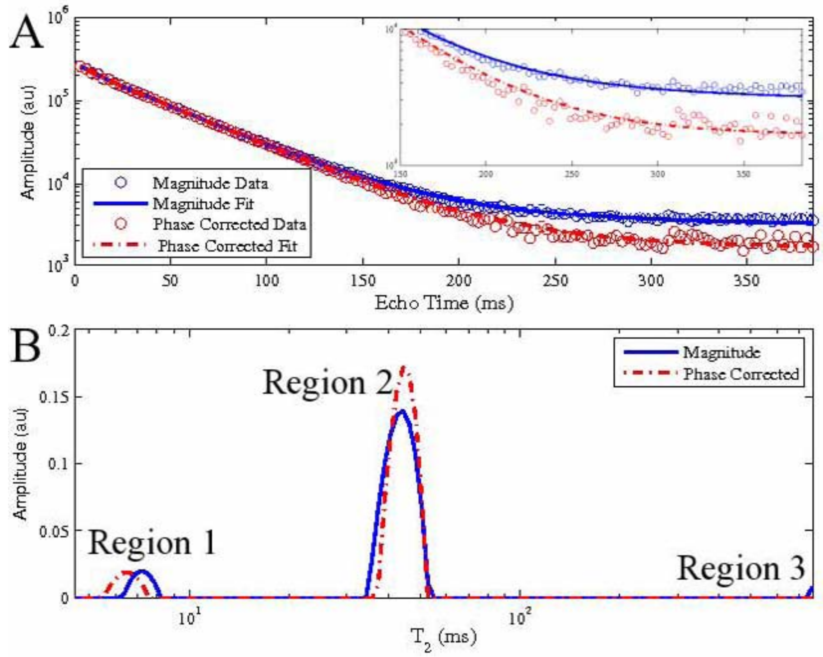

Figure 2: Multi-echo decays and fits (A) and resulting T_2 distributions (B).

Phase correction removed significant artifacts from the real component of the complex signal (Fig 1). The signal decay curves, NNLS fit, and T_2 distributions for both magnitude and phase corrected data are shown in Fig 2. The NNLS fit to the magnitude data falls below the measured values for times beyond 320ms (Fig 2A, inset). However, the NNLS fit to the phase corrected data falls within the measured values at all time points. The T_2 distributions were divided into 3 regions as indicated in Fig 2B. The areas beneath the peaks, gmT_2 times, and standard deviations (in brackets) are shown in the Table 1. Region 3 in the T_2 distribution corresponds to the last component of the T_2 basis set. Therefore, values in Region 3 have no variance, which is indicated by 'na' in Table 1. A significant difference was observed between the magnitude and phase corrected peak areas in Region 3 ($p<0.005$). Indeed, the phase corrected Region 3 peak area was not statistically different from 0. The gmT_2 of the Region 2 peak trended towards longer values for phase corrected data with a p-value approaching significance ($p = 0.084$).

Conclusions: Phase correction of complex multi-echo data retains zero-mean Gaussian noise characteristics. Gaussian noise is an underlying assumption of the NNLS algorithm. Noise rectification in the magnitude data appeared to reduce the rate of T_2 decay. This effect was most apparent in the "tail" of the decay signals, beyond 300 ms, where values in the magnitude data were consistently higher than those in the phase corrected complex data. Accordingly, the phase corrected complex data lacked the very long T_2 peak present in the distributions of magnitude data. Very long T_2 peaks are frequently reported in qT_2 studies, and are usually attributed to cerebrospinal fluid (CSF). However, our ROI was carefully chosen to avoid CSF signal. Furthermore, when an ROI was drawn in a region that was largely CSF (results not shown here) the Region 3 component remained present in the phase corrected data. Future work will focus on improving the phase correction technique used and further examination of the effect of magnitude reconstruction on T_2 distributions calculated using NNLS.

[1] Gudbjartsson & Patz. MRM 34:910-4 (1995)
[2] Laule *et al*. ISMRM 14:446 (2006)
[3] Laule *et al*. ISMRM 14:960 (2006)
[4] Ahn & Cho. IEEE-TMI MI-6:32-6 (1987)
[5] Whittall & MacKay. JMR 84:134-52 (1989)

We acknowledge financial support from the MSSC, AHFMR, and iCORE, and thank D Kelly for assistance.