Quantitative Brain Tissue Mapping Using Fast Spin Echo Imaging

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Introduction: Brain tissue mapping is a key component of numerous imaging applications. Currently, tissue mapping is commonly performed via post-processing intensity threshold segmentation or with specialized data acquisition schemes such as the double inversion recovery pulse sequence. Post-processing methods are limited by their inability to accommodate partial voluming effects while acquisition-based approaches require lengthy scans and provide information on a single tissue. In this work, we modify the hybrid acquisition/post-processing neurological tissue mapping technique proposed by Ikonomidou *et al.* [1] to function with fast spin echo (FSE) imaging to obtain detailed, quantitative maps of cerebrospinal fluid (CSF), white matter (WM), and gray matter (GM). The original technique, developed for co-registration of GM with fMRI data, acquired a series of differing contrast echo planar images (EPI), then inferred the fractional tissue concentration from these images. Mutual EPI distortions between the tissue mapping and fMRI acquisitions improved image co-registration; however, spatial distortions hinder structural and volumetric studies, which require accurate spatial registration. Adaptation to FSE permits higher resolution imaging with fewer artifacts than the original method. Applications include structural investigation of neurological disorders such as cortical dysplasia, multiple sclerosis, and Parkinson's disease. We employ optimization by simulated annealing to select timing parameters for a series of inversion recovery FSE images that maximize tissue T_1 contrast at 1.5 T and permit accurate tissue mapping.

Methods: Assuming three primary neurological tissues (CSF, WM, and GM), the signal intensity (I) can be approximated as a linear combination of the product of fractional concentration (C_i) and transverse magnetization (b_i) for each tissue, according to: $I=C_{csf}b_{csf}+C_{wm}b_{wm}+C_{gm}b_{gm}$ (1). A minimum of three unique contrast acquisitions (different b_i values) permits a least squares estimate of the tissue concentrations. Noise in the fractional concentration maps is minimized with appropriate image contrasts, which are selected via simulated annealing optimization [1, 2]. While constraining the number of scans and the sum of all repetition times, which determines the total scan time, the optimization routine selects either inversion or standard FSE and determines all repetition and inversion times (if necessary) to provide a multi-scan imaging protocol with minimal noise amplification. We opted for five images with a total repetition time of 27.6 s, as outlined in Table 1, since this scheme offers high SNR efficiency with easily implemented acquisition parameters.

Table 1: Timing parameters for five images with a total repetition time of 27.6 seconds.

Image Number	TR (ms)	TI (ms)
1	10000	N/A
2	10000	2620
3-5*	2530	550

***Note that SNR is optimized with three averages of the short inversion time scan rather than five unique contrast images.**

Five sets of coronal images (12 slices, 0.9x0.9x2 mm^3) were obtained on a 1.5 T Siemens Sonata scanner according to parameters listed in Table 1 using phase-preserving real-reconstruction. Total scan time was 13 minutes and 6 seconds with an echo train length of 9.

Results: Raw images, shown in Figure 1, are used to provide a least squares estimate of tissue concentration according to Eq. (1); the resulting tissue maps are shown in Figure 2. This technique provides quantitative estimates of fractional tissue concentrations that are insensitive to partial voluming effects, offering the potential to detect sub-voxel abnormalities.

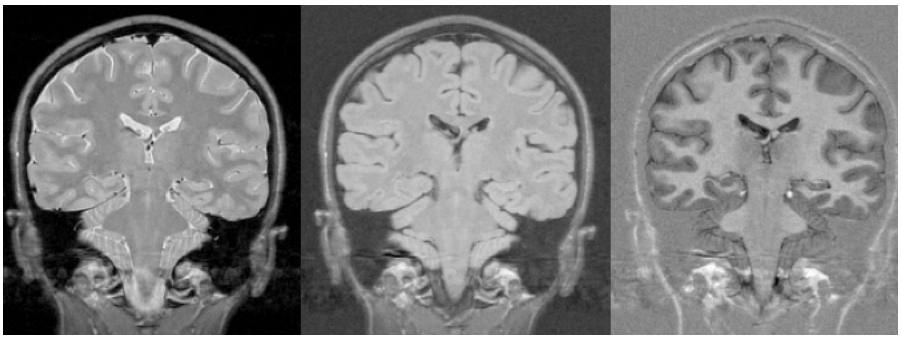

Figure 1: Raw images acquired according to Table 1. Images 1, 2, and 3 are shown (left to right); images 4 and 5 have the same contrast as image 3 and are not shown.

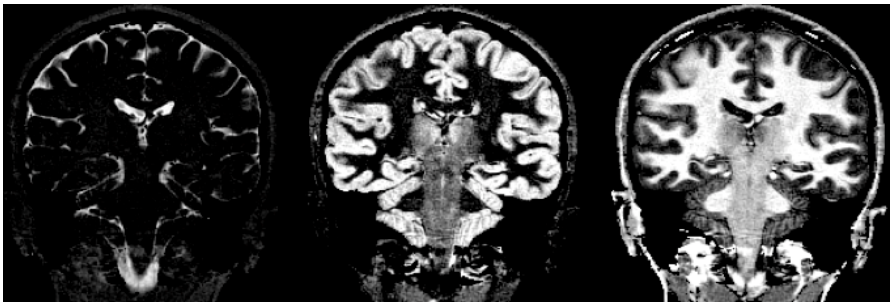

Figure 2: Quantitative CSF, GM, and WM (left to right) fractional concentration maps obtained by a least squares estimate of Eq. (1) from the raw images in Fig. 1. The intensity scale goes from 0 to 1 and the pixel-by-pixel sum of the three images is unity.

Conclusion: Multi-acquisition FSE is well-suited to high-resolution mapping of neurological tissues. This technique is conceptually more robust than post-processing segmentation techniques and accurately renders partial voluming effects. It also provides quantitative information about the three primary neurological tissues, information which is unavailable with double inversion sequences. Potential applications include investigation and diagnosis of neurological disease and improved volumetric measurements.

References: [1] Ikonomidou V. N. *et al*. (2005). Magn Reson Med, *54*(2), 373-85.
[2] Kirkpatrick S. *et al*. (1983). Science, *220*(4598).