Accurate high-resolution T_1 mapping in vivo

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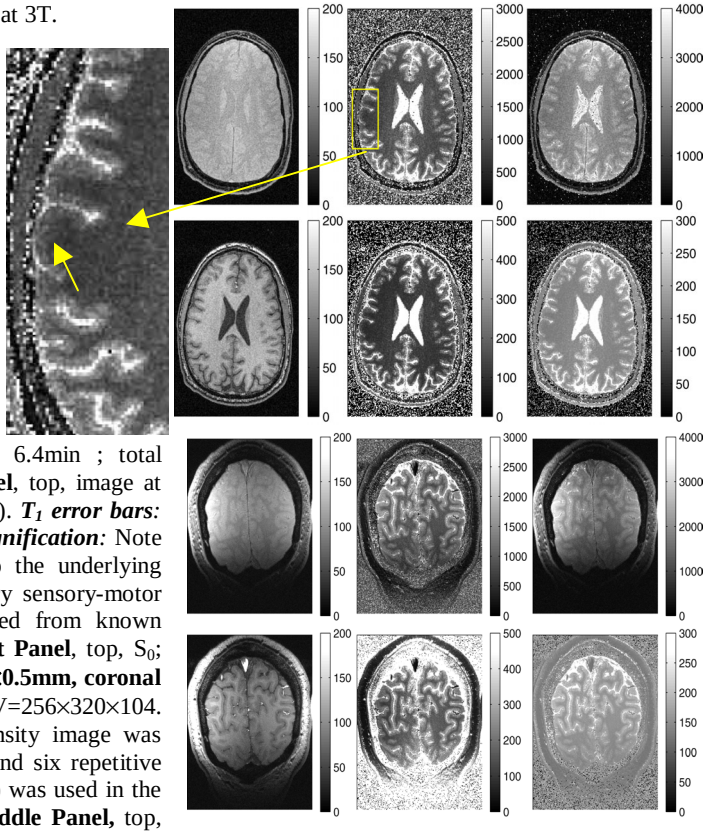
Introduction— T_1 is a characteristic MR property of tissue, strongly influenced by local microstructure such as myelin content. T_1 maps are useful, for example, in studies of brain development and neuropathology [1] and can be used as the basis for brain tissue classification and segmentation. It is therefore important to accurately and quantitatively estimate T_1 *in vivo*, at high spatial resolution [$(0.5\text{mm})^3$ or less]. This is challenging, because of the low-SNR intrinsic to high spatial resolution and the need to constrain the total scan time. We present results for quantitative T_1 mapping at 3T at high spatial resolution $(0.5\text{-}1\text{mm})^3$, with error bars estimated point-wise. Following the suggestions of Wang *et al.* [2] and of Deoni *et al.* [3], we obtained a set of 3D FLASH images collected at a single TR and two flip angles. From these data, T_1 and S_0 and their error bars were estimated. We discuss the potential and limitations of this method for *in vivo* brain imaging at 3T.



Methods and Results— Experiments were performed on a SIEMENS Allegra 3T scanner, using a 3D FLASH sequence. Data were collected using a single TR at two different flip angles chosen as proposed in Ref. [3]. At each voxel, T_1 and S_0 were estimated from $S_i = S_0 \sin\alpha_i \left[1-exp(-TR/T_1)\right]/\left[1-exp(-TR/T_1)\cos\alpha_i\right]$, using a nonlinear least-squares fit in MATLAB. Estimated error bars were calculated for S_0 and T_1, using nonlinear regression theory [4]; our result agrees with the calculation in [5]. The estimated variance follows the general equation $\sigma \times f(T_1, S_0, \alpha_1, \alpha_2)$, where σ is the image variance, calculated from the image background. Estimated variance of T_1 increases monotonically with increasing T_1. T_1 in CSF cannot be easily calculated because $TR/T_1 \approx 0$ for all TRs used with FLASH sequences; therefore, σ_{T1} is also poorly estimated in CSF. **(A) Top Figure, 0.9mm×0.9mm ×1.0mm, transverse slice.** Parameters: TR=15ms, TE=3.69ms, BW/px=200Hz/px, FOV=176×256×144. Acquisition time per volume per flip angle was 6.4min ; total acquisition time was 13min using a head coil (Nova Medical). **Left Panel**, top, image at $\alpha=4^o$, bottom, image at $\alpha=23^o$. **Middle Panel,** top, T_1(ms); bottom, σ_{T1}(ms). ***T_1 error bars:*** Notice that σ_{T1} increases with increasing T_1. ***Middle Panel Insert, see Magnification:*** Note that we can reliably detect differences in T_1 across the cortex due to the underlying differences in myelination. In particular, the T_1 of gray matter in primary sensory-motor cortex is noticeably smaller than other nearby areas as to be expected from known differences in the size of the heavily myelinated cortical layer IV. **Right Panel**, top, S_0; bottom, σ_{S0} (arbitrary intensity units). **(B) Bottom Figure, 0.5mm×0.5mm×0.5mm, coronal slice**. Parameters: TR=15ms, TE=7.21ms, BW/px=90Hz/px, FOV=256×320×104. Acquisition time per volume per flip angle was 6.7min and each intensity image was averaged 6 times; total acquisition time was 80min for both flip angles and six repetitive acquisitions per flip angle. A 4-channel occipital coil array (Nova Medical) was used in the experiment. **Left Panel**, top, image at $\alpha=4^o$, bottom, image at $\alpha=23^o$. **Middle Panel,** top, T_1(ms); bottom, σ_{T1}(ms). **Right Panel**, top, S_0; bottom, σ_{S0} (arbitrary intensity units). ***T_1 error bars:*** The background variance $\sigma \approx 8$ in both images [note, (A) is without occipital coil, (B) is with occipital coil], implying an average image SNR of about 10 (SNR of intensity images acquired with FLASH) in each experiment, with a maximum SNR value of about 15 nearer the coils. T_1 error bars range from about 10% of T_1 values in regions of high SNR and in white matter in general, to about 17% in gray matter, and are much larger in CSF. **(C) SNR comparison:** The decrease in SNR in going from 1mm to 0.5mm is expected to be a factor of 8; by averaging and using a surface coil this decrease can be mitigated, and these two sets of T_1 measurements have approximately the same accuracy.

Discussion— T_1 error bars of 10-17% are easily obtained at 0.9mm×0.9mm×1.0mm in 13min total scan time at 3T, using a head coil and whole-brain acquisition. The same accuracy was achieved with 80min total scan time at $(0.5\text{mm})^3$ with a surface array. If higher T_1 measurement accuracy or higher spatial resolution are needed, however, this method may become impractical. In order to routinely measure T_1 at 0.5mm resolution, it is necessary to decrease the imaging time. We intend to implement a scheme in which we increase TR and restrict the FOV using outer volume suppression. For example, using TR 35ms, TE○10ms, FOV=112×384×112, [$(0.5\text{mm})^3$] and averaging three times has the same SNR as in (B) but is realizable in half the scan time.

Conclusion— We have point-wise estimated T_1, S_0, and σ_{T1}, σ_{S0} at high spatial resolution [$(0.9\text{mm})^2 \times 1\text{mm}$ and $(0.5\text{mm})^3$] at 3T. Error bars, as expected, increase with increasing T_1.Accuracy of 10-17% in T_1 can be achieved with 13min total scan time using only a head coil. The same level of accuracy required 80min and a 4-channel occipital coil array at $(0.5\text{mm})^3$.

References—

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