Normal Regional T_1 and T_2 Relaxation Times of the Brain at 3T

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Introduction:
Traditionally, T_1-weighted images have been used to assess morphology of the brain, while T_2-weighted images highlight diseased areas. Recently, however, there has been a trend to apply quantitative measurements to a variety of brain diseases, having found that quantifiable abnormalities are detectable in normal-appearing gray and white matter in diseases such as multiple sclerosis [1]. Quantitative measurements have the potential to be used for establishing objective diagnostic criteria. They also can be used to detect subtle changes over time, which is useful for monitoring progression of disease or response to treatment. We propose that, as a supplement to visual review of T_1-weighted and T_2-weighted images, calculation of T_1 and T_2 relaxation times will prove useful as a quantifiable measure of potential brain abnormalities. As a reference for future studies of disease, it is helpful to have a thorough description of what is normal. Our purpose in performing the current study is to establish reference values and estimate normal variation. To this end, we have produced an extensive table of normal values for different regions of the brain, covering more regions with more subjects than previous published reports.

Method:
19 healthy volunteers were studied. We used the method for calculating T_1 and T_2 maps described by Deoni *et al.*[2]. This method is based on steady-state imaging with T_1 and T_2 information derived from either spoiling or fully refocusing the transverse magnetization following each excitation pulse. T_1 is extracted from a pair of spoiled gradient recalled echo (SPGR) images acquired at optimized flip angles. This T_1 information is combined with two refocused steady-state free precession (SSFP) images to determine T_2. The optimum angles were determined by a method described by Deoni *et al.*[3] using a weighted least-squares algorithm. We further verified the optimum angles as well as accuracy of our data using a phantom consisting of a water bath containing 1 tube of water and 6 tubes of various aqueous concentrations of Gd-DTPA designed to achieve T_1 values of 50, 100, 200, 500, 1000, and 1500 ms. We collected FFE images of the phantoms well as a healthy volunteer using angles of 2º, 4º, 6º, 8º, 10º, 12º, and 14º, and have confirmed 2º and 12º to be the optimum combination of angles for measurement of T_1 in the brain. We did the same for the T_2 measurement, using angles of 5º, 15º, 20º, 55º, 60º, and have confirmed 20º and 60º to be the optimum angles.

Scanning parameters and image analysis
T_1 map: FFE technique; matrix = 256 x 256; FOV = 240mm; slice thickness = 3mm; flip angles 2º and 12º; TR = 8.1ms; TE = 3.9ms; 2:06 min. per acquisition.
T_2 map: BFFE technique; matrix = 256 x 256; FOV = 240mm; slice thickness = 3mm; flip angles 20º and 60º; TR = 5.9ms; TE = 2.2ms; 1:32 min. per acquisition.
Scanner: 3T Philips Intera with SENSE head coil.
Analysis: The images were analyzed using Medical Imaging Processing, Analysis and Visualization (MIPAV) software from the NIH. Regions of interest (ROIs) were placed bilaterally in 23 different anatomical regions of the brain. To maintain consistency, the ROIs were all drawn by one person; to ensure anatomical accuracy, this person was a trained radiologist. Examples of the ROIs can be seen in the Figure.

Results
T_1 and T_2 relaxation times for 23 anatomical locations are presented in the Table. These values are pooled across all subjects. The variance is highest, in general, where the number of points in the ROI is small, such as in gray matter and in small structures such as the red nucleus, globus pallidus, and medulla. Variance is also high at the periphery of the sensitive volume of the head coil where signal-to-noise is poorer, such as in the medulla and cerebellar white matter. For a given anatomical location, the standard deviation (SD) seen in an ROI within an individual is comparable to the SD of that ROI for the pool of volunteers as a whole with no outliers, suggesting that the volunteers do not differ significantly from each other.

Calculated T_1 and T_2 Values, by Brain Anatomical Region

Brain Regions	T_1 (ms) ± SD FFE, N=19	T_2 (ms) ± SD BFFE, N=10
Frontal white matter	**805 ± 89**	**49 ± 9**
Parietal white matter	**837 ± 103**	**64 ± 4**
Occipital white matter	**784 ± 64**	**58 ± 5**
Temporal white matter	**923 ± 67**	**57 ± 5**
Centrum semiovale	**806 ± 114**	**60 ± 7**
Corpus callosum, genu	**896 ± 87**	**46 ± 16**
Corpus callosum, splenium	**984 ± 92**	**62 ± 6**
Frontal gray matter	**1283 ± 163**	**76 ± 12**
Parietal gray matter	**1204 ± 205**	**92 ± 23**
Occipital gray matter	**1232 ± 217**	**88 ± 25**
Temporal gray matter	**1381 ± 99**	**73 ± 13**
Insular gray matter	**1664 ± 153**	**101 ± 10**
Caudate head	**1563 ± 148**	**60 ± 19**
Putamen	**1403 ± 160**	**70 ± 9**
Thalamus	**1494 ± 151**	**73 ± 6**
Substantia nigra	**1421 ± 108**	**67 ± 5**
Red nucleus	**1260 ± 99**	**68 ± 10**
Hippocampus	**1697 ± 134**	**94 ± 11**
Amygdala	**1821 ± 118**	**90 ± 9**
Pons	**1353 ± 71**	**63 ± 14**
Cerebellum, white matter	**1081 ± 182**	**76 ± 17**
Cerebellar peduncles	**1150 ± 71**	**66 ± 17**
Medulla	**1146 ± 219**	**68 ± 27**

Conclusion
For locations for which values have been published, our values for T_1 and T_2 relaxation are comparable to other published data [4,5]. These values should be able to serve as a set of reference relaxation times for a variety of potential investigations of disease states.

References
1. A. Castriota-Scanderbeg, *et al*. Mult. Scler. **10**(5):556-561 (2004)
2. Sean C.L. Deoni, *et al*. MRM **49**(3):515-526 (2003)
3. Sean C.L. Deoni, *et al*. MRM **51**(2):194-199 (2004)
4. Janaka P. Wansapura, *et al*. JMRI **9**(4):531-538 (1999)
5. Neil Gelman, *et al*. MRM **45**(1):71-79 (2001)

Examples of anatomical ROIs drawn on a calculated T_1 map.