Quantitative water content assessment using a single-scan multi-parameter mapping technique and spectral processing of a multiple gradient echo acquisition

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Introduction: MRI characterization of brain lesions has been limited to qualitative assessment of anatomical distortion derived from visual assessment of signal change. Quantitative water assessment may support this characterization and diagnosis by definitively identifying areas of edema. It has been shown that water content in the brain may be assessed when proton density is measured from a multiple fast gradient echo (MFGRE) sequence. This is only feasible when the signal is properly corrected for all factors contributing to the gradient echo (GRE) signal, including T2*, T1, the spatially varying effective flip angle of the sequence, and the sensitivity of the receiver coil [1,2]. While receiver coil intensity correction can be derived from calibration scans, other corrections must be measured through multiple dedicated sequences. In this study, we propose a method for assessing brain water content that incorporates a single sequence [3,4] that quantifies the tissue T1 relaxation and the radiofrequency B1 field necessary to derive the additional correction factors. We also utilize an autoregressive moving average model [5] of the complex gradient echo train signal.

Theory: Due to the rapid relaxation properties of macromolecules, their signals are generally not detected in a GRE sequence. Fitting the echo train signal back to TE=0 will remove the T2* weighting of the gradient echo signals [1,2,6]. Here this is calculated using single-peak autoregressive moving average spectral modeling of the complex MFGRE signals [5], rather than fitting the magnitude signals. The image is then corrected for other factors:

$$S_{PD} = S_0 \cdot C_{flip} \cdot C_{T1Sat} \cdot C_{coil} \cdot C_{temp}$$

Where S_{PD} is the proton density signal, S_0 is the magnitude of the gradient echo signal fitted to TE = 0, C_{flip} is a correction for the effective flip angle, C_{T1Sat} is a correction for the saturation due to the GRE sequence, C_{coil} is a correction for the receiver coil sensitivity, and C_{temp} is a correction for the temperature of a density reference. These corrections can be derived from measurements of T1, B1, and the receive field. Qmap is a saturation recovery fast spin echo (FSE) sequence acquired at multiple saturation delay times, which enables the mapping of both T1 and effective flip angle (α_{eff}) of the saturation pulse [3]. Thus a scaling factor can be applied to the prescribed flip angle of the MFGRE sequence to determine the effective flip angle (α_{eff}), which can be used to scale the MFGRE signal by $\sin(\alpha_{eff})$. α_{eff} can also be combined with the T1 measurement to calculate the quantitative effect of signal saturation on the MFGRE signal based on the Ernst equation:

$$C_{T1Sat} = (1 - \cos(\alpha_{eff}) \cdot e^{TR/T1})/(1 - e^{TR/T1})$$

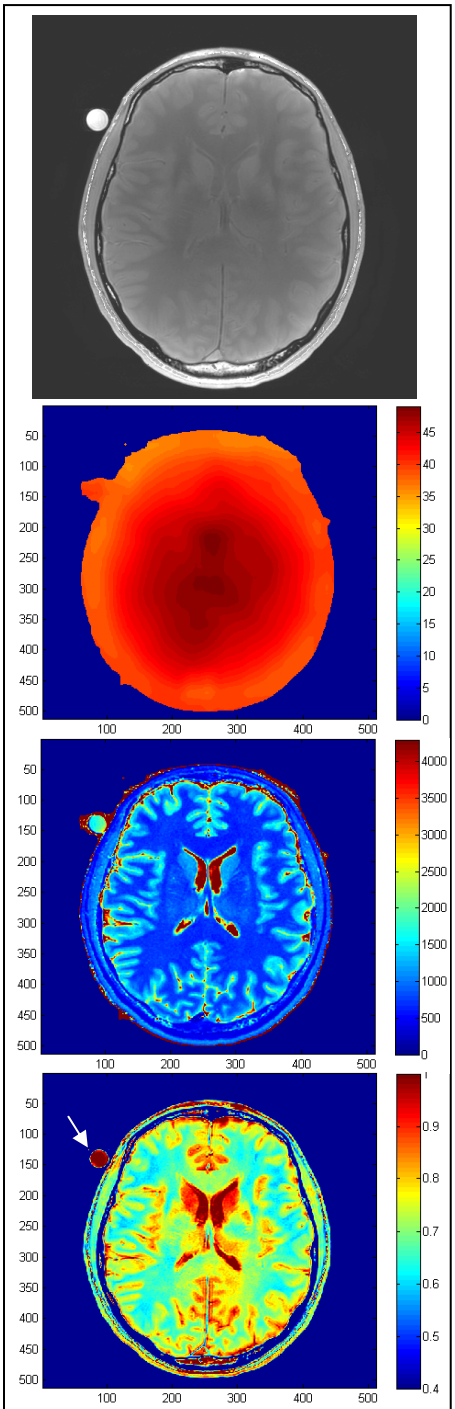
A simple coil correction based on the ratio of the receive coil images to the body coil image can then be applied. When imaged with a water reference source, absolute water density can be calculated by the ratio of a pixel's value to that of the water reference.

Methods: Five volunteers were scanned using a 32-ch head coil and a 3.0T MR imager (MR750, GE Healthcare, Waukesha, WI), with the following four sequences: 1) a GRE calibration scan with receiver coils, 2) a repeat of the calibration scan using the body coil, 3) Qmap, and 4) MFGRE. Both Qmap and MFGRE were scanned with identical geometries: FOV = 22.0 cm, matrix = 320x256, slice thickness = 4.0, slice gap = 1.0, number of slices = 30. Additional sequence parameters for Qmap were: bandwidth = ±25 kHz, TE1 = 22, TE2 = 87, TR = 4000. Additional parameters for MFGRE were: bandwidth = ±125 kHz, number of echoes = 16, TE = 2.4 to 53.4, TR = 2200, flip = 60. A vial of distilled water taped to the skin provided the water reference. The Qmap complex raw images were processed with an evaluation version of SyMRI Diagnostics Brain Studio (SyntheticMR, Linköping, Sweden) to produce maps of the T1 and B1 dependent scaling values. All additional processing as described above was performed with MATLAB (Mathworks, Natick, MA). Receive coil intensity correction was provided by low pass filtering the body coil calibration scan image divided by the receiver coil calibration scan image.

Results: Water content for white matter and gray matter were in the range of 60-70% and 70-80%, respectively, which are in general agreement with [2,5]. Some unstable values were identified at the fat/water interfaces, though generally these areas were away from the brain.

Conclusions: We have demonstrated a method for correcting an MFGRE acquisition with parameters derived from Qmap to produce a measure for absolute water content. It is noted that other quantitative measurements (T2, T2*, chemical shift) are extracted from the two sequences, and together this complimentary information may provide a complete quantitative assessment for characterization of a variety of diseases in the brain. Future work will investigate advantages of a 2-peak model near fat/water interfaces and within mixed tissue environments.

References: [1] Neeb H et al, NeuroImage 2006, 31:1156-68. [2] Neeb H et al, NeuroImage 2008, 42:1094-1109. [3] Warntjes JB et al, Magn Reson Med 2008, 2:320-9. [4] West J et al, Eur Radiol 2012, 5:998-1007. [5] Warntjes JB et al, Magn Reson Med 2007, 3:528-37. [6] Taylor BA et al, Med Phys 2009, 36:753-64.



TE=0 image (top) produced by backfit of the gradient echo train signal, followed by effective flip angle in degrees and T1 map in msec as produced with Qmap. Water content map (bottom) is shown as a fraction of the water reference (arrow).