Brain Water Content Measurement and Visualization with Applications to Hydrocephalus

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Introduction

Brain water content measurement has important clinical applications in detecting brain disorders (1). A linear relationship between the inverse of the brain tissue water fraction and the inverse of T_1 has been found at various magnetic field strengths (1, 2). A full-brain T_1 mapping technique through inversion recovery fast spin echo (FSE) imaging with time-efficient slice ordering (TESO-IRFSE) was developed by Zhu and Penn (3) on a 3T system and was applied to measure brain tissue water content. Demonstrated here are brain water content measurement and visualization on normal and hydrocephalic brains.

Methods

Nine normal subjects (five males, four females, and 35 ± 10 years of age) and one 83-year-old hydrocephalic patient have participated in this study. The TESO-IRFSE pulse sequence has been implemented on a GE Signa 3T MR scanner equipped with a standard quadrature bird-cage head coil (GE Medical Systems, Milwaukee, WI). For each subject, 12 slices were acquired with 256×128 matrix size, 4 mm slice thickness with 4 mm gaps, 24 cm field of view, 8.1 ms TE, 8.1 ms echo spacing, ±31.25 kHz receiver bandwidth, 3 s TR, 6 different time of inversion (TI) conditions for each slice, and 50 ms between the non-selective spin inversion and the starting of the multi-slice FSE echo train. After a set of images were collected, T_1 maps were generated based on curve fitting (3).

The nine normal subjects represent ranges of gender and age, which have been designed to cover the similar ranges of the 27 normal subjects (16 males and 11 females, and 34 ± 8 years of age) used in the water content measurement by Fatouros et al. (1). Since the inverse of the tissue water fraction by weight (f_w) and the inverse of T_1 can be described by a clear linear relationship of $\frac{1}{f_w} = A + B\frac{1}{T_1}$, the constants A and B were found after a linear regression calibration process between $1/f_w$ and $1/T_1$ at seven regions of interest (frontal white matter, posterior white matter, genu of corpus callosum, splenium of corpus callosum, head of caudate nucleus, putamen and thalamus) and overall white matter. These regions have homogenous tissue types and are appropriate to use for calibration. The values of $1/f_w$ were from the data published by Fatouros et al. (1) and the values of $1/T_1$ were from the nine normal subjects measured on the 3T MR scanner.

The brain water content map can be visualized directly. The water content average of pixels at the same distance to the ventricle wall is also informative for investigating hydrocephalic brains. In the examples here, groups of pixels at the same distance from the ventricle wall and within a radial distance of four pixels were averaged.

Results and Discussion

Based on the linear regression calibration process, the relationship of $\frac{1}{f_w} = 0.926 + \frac{0.374}{T_1}$ (with a 0.918% standard error of estimate) has been found for the data acquired with the TESO-IRFSE technique and the associated protocol on the 3T scanner. A systematic underestimation of the T_1 values was found from the TESO-IRFSE technique, but was correctable based on a linear relationship between the measured and true $1/T_1$ values. Therefore, a clear linear relationship between the measured $1/f_w$ and $1/T_1$ values is not changed. The water contents (weight %) measured with the TESO-IRFSE T_1 mapping technique at various regions of the nine normal brains are listed: 68.8±0.9% at frontal white matter, 69.8±0.7% at posterior white matter, 67.4±1.2% at genu of corpus callosum, 68.3±0.9% at splenium of corpus callosum, 79.2±0.5% at head of caudate nucleus, 78.0±0.5% at putamen, 75.9±0.5% at thalamus, 69.7±0.7% at overall white matter of brain and 82.8±0.6% at overall gray matter of brain. These values correspond well with those reported by Fatouros et al. (1). Brain water content maps and distributions of a normal brain (Figure 1) and a hydrocephalic brain (Figure 2) are shown. The comparison shows elevated water content in the white matter in the hydrocephalic brain. The effect of shunting on brain water content for hydrocephalic brains will be investigated.

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References

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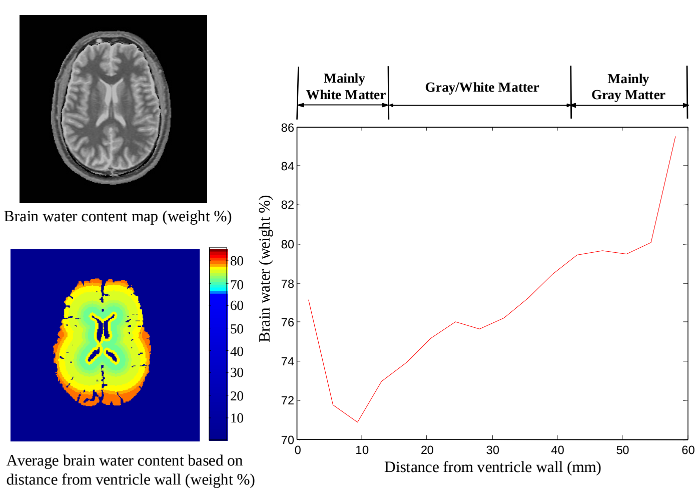

Figure 1. Brain water content map and distribution of a normal brain.

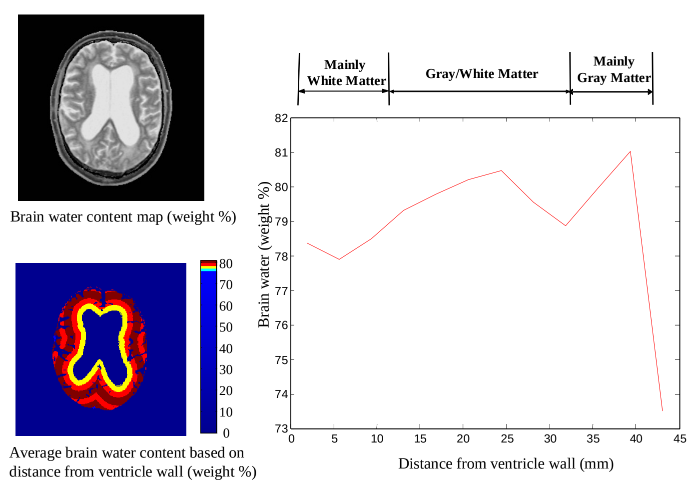

Figure 2. Brain water content map and distribution of a hydrocephalic brain.