Water Mapping of the Whole Brains of Infants Using an FSE Sequence at 3.0 T

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Introduction

Water content is an important variable in brain development because it is closely related to the progress of myelination in the central nervous system of humans. Water content also plays a central role in many cerebral physiological and pathological conditions. MRI offers a non-invasive, safe technique for measuring and mapping water content in the brain. Water content changes throughout the lifespan, but most markedly in early life, producing corresponding changes in T_1 and T_2 relaxation times. These changes lead to alterations in contrast and even reversion in MR images. A number of methods and applications for measuring water content in the brain with MRI have been reported in the last decade. Several have been quantitative techniques; however, to our best knowledge, they have all been performed in adults or children only, not in infants. Here we present a preliminary study of mapping water content quantitatively in the brains of healthy infants using multi-slice images acquired with a fast spin echo (FSE) pulse sequence.

Methods

We studied four healthy infants, ages 4 to 10 days. The infants were fed, swaddled, and placed carefully into the scanner with gentle head restraint and earplugs. EKG and pulse oximetry were monitored during the scan. Scans were stopped immediately if an infant awakened or cried. Informed parental consent was obtained for each infant, and the protocol was approved by the local IRB.

All measures were performed on a GE 3T scanner with EXCITE 12 (GE Medical Systems, Milwaukee, WI) and an 8-channel head coil. Standard GE pulse sequences were used with the following parameters. (1) Scout image: 3-P Localizer, TR/TE = 86.9/1.8 ms. (2) T_2 measurement: Fast Spin Echo (FSE) sequence; TR = 3500 ms; nominal TE = 35, 70, 105, 140, 175, 210, 245 ms; SAR (pk) = 3.0 W/kg; SAR(est) 1.5 W/kg; Measurement time = 7 minutes. (3) T_1 measurement: Inversion Recovery Prepared FSE sequence; FOV = 190x128 mm; Slice thickness 3 mm; Number of slices = 38; Spatial encoding = 192x128; TR/TE = 10,000/13 ms; TI = 60, 300, 750, 1500, 3000 ms; Scan time = 18 minutes. The maximum SAR was 2.28 W/kg and the average SAR was 1.14 W/kg. CSF was used as an internal reference for relative water content, because water fraction of CSF is over 98% and is very stable.

All images were acquired in magnitude mode in DICOM format. Image preprocessing included motion correction and brain extraction. T_2 values were first determined voxelwise for the phantom and brain by fitting the simple model function $S = S_0^* e^{-TE_{eff}/T_2}$, where S_0^* is the partially saturated nominal spin density and TE_{eff} is effective echo time. T_1 and nominal spin density (S_0) distributions were obtained by fitting signals in each voxel to the following three variable model function $S = S_0(1 - ke^{-TI/T_1} + e^{-(TR-TE_{last})/T_1})$, where TE_{last} is the TE of the last echo and k is a variable accounting for imperfect flip angles. T_2 values were used to extrapolate the S_0 to TE = 0. The corrected $S_{0,w}$ for the phantom was considered to be the signal of 100% water and was used to calibrate the water content against the S_0 in the infants' brains. Water mapping was generated with the calibrated voxel signals $S_{0,c}$. Tissue classification was performed based on their T1 values: voxels with T_1 values within the ranges of 1200 to 1500 ms and 1600 to 2200 ms were classified as grey matter and white matter, respectively. Values for water content in the selected ROI were presented as the means and standard deviations of their voxel values in the corresponding ROI. Processing programs were written in Matlab [The MathWorks, Inc, Natick, MA].

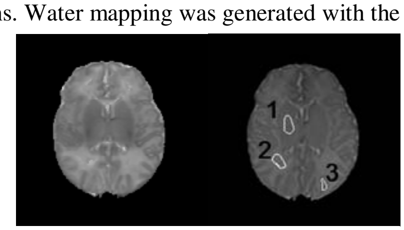

Fig. 1 A T1 map (L) and a water map. (R).

Results and Discussions

Figure 1 shows an example of a T_1 map and a water content map in the axial plane. The T_1 map exhibits a clear distinction between white matter and gray matter, but with contrast opposite to that found in adults. The water map shows a similar contrast pattern because water content and T1 values correlate closely. Table 1 shows the numerical values of T_1 times and water content for 3 brain regions. The average T_1 values are about 2300 and 1500 ms for white matter and gray matter, respectively. The values here are about 30% percent larger compared with values obtained with the FSE sequence and similar parameters at 1.5 T [1]. Our results agree with a previous report that T_1 values increase 14% to 30% at 3T compared to 1.5 T [2]. However, our values are lower than those in another report [3], where the T_1 values are 2500 to 3000 ms for white matter and 2000 to 2500 ms for gray matter, using a multiple readout pulses sequence [4]. Differing pulse sequences used for T_1 measurement may have caused this discrepancy. Although the overall variation of T_1 values was small, the residue of some individual voxel fittings was large. Water fraction is approximately 88% in water matter and 75% in gray matter, as compared to CSF. Error sources include misregistrations and field inhomogeneities.

Regions	1	2	3
T1 (ms)	1538.4±63.9	2311.8±148.0	1791.0±69.0
Water fraction	76.3±1.4 (%)	88.3±3.2 (%)	73.5±1.1 (%)

Conclusion

Our preliminary mapping of T_1 times and water content using an FSE pulse sequence shows the feasibility of measuring water content and its changes in the brains infants. Future technical studies should evaluate pulse sequence accuracy, correct for B0/B1 inhomogeneities, and calibrate water fraction with absolute water reference, so as to apply this water mapping technique to document changes of water content in infant's brains.

References [1] Jones RA. et al. AJR 2004;182:367-372. [2] Williams LA. et al. Radiology. 2005;235:595-603. [3] Lu HZ. et al. JMRI. 2005;22:13-22. [4] Brix G etal MRI 1990;8:351-356.