Phantom Validation of Inversion-Recovery Fast Spin Echo T1 Mapping: Importance of Careful Temperature Control

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Purpose

1) To demonstrate the reproducibility (precision) of an inversion-recovery fast spin echo T1 mapping method. 2) To show that because of the large temperature dependence of T1 (~2.2% per degree C at room temperature), MRS validation of T1 methods in phantoms must be performed at the same temperature as the MRI method being validated.

Introduction

For T1 mapping to become useful clinically, a fast, accurate, and precise method with good image quality is necessary. A Fast Spin Echo sequence can speed up data acquisition of a precise and accurate inversion-recovery method (1) with little loss of image quality. Methods of measuring T1 relaxation times by MRI often are validated by comparing the MRI measurements to MRS measurements in phantoms (1,2). Details of such phantom validation measurements are usually not given. Attempts to validate an inversion-recovery fast spin echo T1 method by repeating the MRI measurements on different days and in two different magnets resulted in large variations (>10%) in the calculated T1 times, despite very small variations (<1%) in consecutive measurements in one magnet. These variations appear to be due to temperature fluctuations.

Methods

T1 was measured by an inversion-recovery fast spin echo method, TR/TE = 2500/17 ms, echo train length ETL = 4, six TI from 50 to 2400 ms, FOV = 15x20, matrix = 96x256. The entire set of 6 images was acquired in less than 9 min. Each T1 map was produced with the equation

$$\text{Signal Intensity} = A + B \exp(-TI/T1)$$

which gives correct T1 values despite imperfect pulses (abstract submitted for this meeting). Some data were acquired with ETL/TR = 1/2500, 2/2500, 8/2600 or 16/2700, and with 144 or 192 pase encodes for ETL = 16.

Phantoms included ten plastic tubes with 0 - 0.4 mM Gd-DTPA (Magnevist®, Berlex Laboratories) in distilled water. The T1 range was about 430 ms to 2600 ms at room temperature. For studies at different temperatures, the phantoms were surrounded by water to slow down heat transfer between the tubes and the air. The phantoms and water bath were cooled in a refrigerator for two days, then heated in a microwave oven to different temperatures. The temperature was measured in one tube and the surrounding bath before and after the imaging. Temperatures were interpolated to a single average temperature. Fitting data with a different temperature for each TI time did not change the results significantly.

Results

The image quality deteriorated slightly with ETL = 2 or 4, and was significantly worse for ETL = 8 or 16, even with increased phase encode steps for ETL = 16. ETL = 4 was chosen for further studies.

T1 maps of the brain of a volunteer demostrated good precision. When 5 T1 maps were acquired during a single exam, the coefficient of variation (CV) over 12 different white and gray matter areas was 1.3% ± 0.3%. When T1 maps were made with only 4 TI times (50, 500, 900, 2400 ms), T1 increased by 0.2% ± 0.3%. When T1 was calculated from the average intensity for each region instead of for each pixel, the T1 values changed by -0.1% ± 0.1%. This shows that calculated T1 values are not significantly affected by the exact method of calculation.

When T1 was measured five times in a row in phantoms, the CVs were less than 0.6% except at the longest T1 (CV = 0.9%). The CV including different ETL and matrix sizes was 1.0% or less except at the longest T1 (CV = 1.7%). When measurements were repeated over a few months and on two different magnets, T1 times were uniformly higher or lower on certain days, with an overall range of greater than 10% in every phantom. When T1 was measured at different temperatures, T1 increased about 2.2% per degree C in every tube containing Gd-DTPA. Similar results were found in two tubes of gelatin with no Gd.

Discussion

The increase in T1 with temperature has been reported in Gd-DTPA solutions (3) and other ion solutions and gels (4), and has been studied as an in vivo thermometer (5). However, this effect is usually neglected in reports of new T1 methods being validated by MRS measurements in phantoms. It is likely that temperature changes caused a 2-parameter fit to appear as good as a 3-parameter fit in phantom validation of an inversion-recovery T1 method (1). Compared to MRS T1 values, 3-parameter T1 values were 3.8% too high, and 2-parameter values were 3.0% too low. If the temperature during the MRI measurements were 2˚ C higher than during the MRS measurements, the true MRI T1 would be ~4.4% higher than originally believed. Thus, the 3-parameter fit would have been 0.6% too low, and 2-parameter value would have been 7.4% too low. Later results showed that a 3-parameter fit is needed for accurate T1 values (2).

Conclusions

1) An inversion-recovery fast spin echo T1 map is very reproducible, even with only 4 TI times. 2) MRS validation measurements should be performed immediately before or after the MRI method being validated, and after the samples have equilibrated with the environment.

References

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