AN FMRI PHANTOM BASED ON THE ALIGNMENT OF MOLECULAR DIPOLES WITH AN ELECTRIC FIELD

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Introduction

Multicenter MRI research studies are advantageous as they increase the statistical significance of results, especially in the case of rare diseases, and promote the interaction and collaboration of researchers.[1] This is particularly true in functional MRI (fMRI) studies where it is often difficult to register large populations at a single site. However, these studies unavoidably introduce variations in the results due to differences in imager vendor, field strength, pulse sequence implementation, software, hardware, and post processing methods at the participating sites. This makes combining data from the sites risky and necessitates a rigorous quality assurance (QA) program. An important part of an fMRI QA program is the ability to detect a difference in T_2* comparable to the blood oxygen level dependent (BOLD) signal. Two types of phantoms have been proposed for this purpose. One uses agarose gel, due to its similarity in the relaxation times T_1 and T_2 to gray matter.[2] The other uses an electric current in a wire to change B_o[3] or B_1[4], and thus lead to the change of the signal. Only one of these attempts to model the transient nature of the BOLD signal, but at a significantly slower rate.[2] We present a phantom in which the T_2 of a polar liquid can be changed with the application of an electric field, similar to that reported for T_1.[5] The electric field aligns the dipole moments of the molecules in the liquid, thus changing the distribution of molecular motions and T_2. The alignment process is similar to the alignment of a liquid crystal (LC) in a LC display by an electric field. The rates of alignment and return to the unaligned state will depend on the size of the molecule. As a first step towards developing a phantom with a switchable T_2 value, we have identified a non-viscous liquid comprised of small molecules with a large dipole moment that should allow a rapid change in T_2 and the ability to mimic the BOLD response. This study demonstrates the ability to change T_2 with an applied electric field.

Materials and Methods

The phantom consists of a geometric grid, eight vials with solutions of known T_2 values, and a cylindrical electrical cell. (See Fig. 1.) The vials contain aqueous solutions of 2.4% gelatin with concentrations ranging from 10.7 to 23.8 mM $CuSO_4$. The Teflon® electrical cell has an inside diameter (ID) of 2.2 cm and a 2 cm distance between two circular, 23 μm thick, copper electrodes. The cell is filled with propylene carbonate (Sigma-Aldrich) which has a relative dielectric constant of 64 and viscosity of 2.4 cps. All the above components are located inside a 17.8 cm ID poly(methyl methacrylate) (PMMA) cylinder filled with 18 MΩ·cm water. Electrodes are connected by #36 and #26 Cu wire to plugs outside the PMMA cylinder, to which a 233 V battery pack is connected via a 3 meter pair of wires. Images were recorded with a GE Signa 1.5 T scanner, a quadrature head coil, 20 cm field-of-view, 1 cm slice thickness, and 256×192 matrix. T_2 values were determined from five, four-echo spin echo sequences with a 1 s repetition time and 17 images between 15 and 140 ms. The proton signal from the electrical cell was measured with the region-of-interest function. The T_2 value was calculated using a linear, least-squares algorithm implemented in Microsoft Excel®.

Results

Fig. 2 presents a magnetic resonance image from a slice through the phantom. The electric cell can be seen in the center of the image. An artifact from the wire attached to the electrode and passing through the water is also visible in the image. The propylene carbonate signal as a function of TE, both with and without the applied electric field is plotted in Fig. 3. The best fit to the data yields T_2 values of 45 ms without, and 36 ms with an applied electrical field (E) of 1.18×10^4 V/m.

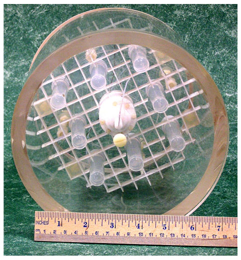

Fig 1. Phantom image.

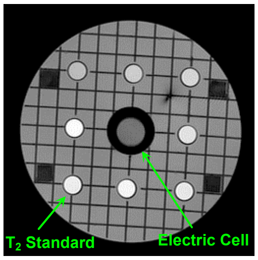

Fig 2. MR phantom image.

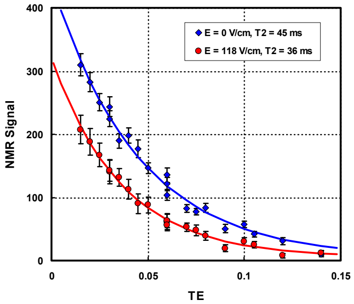

Fig. 3. Relaxation curves for the propylene carbonate NMR signal as a function of TE with and without applied electric field. Solid lines are the best exponential fit to the data. The measured T_2 values are 45 and 36 ms for E = 0 and 1.18×10^4 V/m respectively.

Discussion/Conclusions

The results show that T_2 value of propylene carbonate can be changed with the application of an electrical field across the liquid. The T_2 valued changed from 45 ms to 36 ms with an applied field of 1.18×10^4 V/m. With TE=30 ms, this change in T_2 alters the signal by approximately 15%, a value comparable to the 5-20% reported for the BOLD signal.[2,6] The T_2 value should be rapidly switchable due to the low viscosity propylene carbonate, thus allowing T_2 changes comparable in speed to the BOLD signal. The artifact from the looped wire from the electrode is far enough away from the electric cell that it does not affect the signal from the propylene carbonate.

References

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