A study of MRI contrast agent effects on the proton resonance frequency and on T2*

L. de Rochefort[1], R. Brown[1], M. R. Prince[1], and Y. Wang[1]

[1]Radiology, Weill Medical College of Cornell University, New York, NY, United States

PURPOSE

Paramagnetic and superparamagnetic contrast agents (CA) modify the magnetic field, relaxation rates, and resonant frequencies of neighboring protons [1]. T1 reduction has been widely used, particularly for contrast-enhanced MR Angiography (CEMRA). However, the frequency shift has been less utilized. This shift depends on the agent type, its concentration, B_0, and geometrical configuration. Recently, selective excitation or saturation has been proposed for contrast generation [2-5]. Methods have been used to measure linear media susceptibility [6] or to separate tissues with distinct susceptibilities [7]. However, fewer methods have been introduced which take advantage of the geometrical aspects of susceptibility effects. Here we investigate these topics on a vascular-like curved phantom simulating first pass CEMRA. We make use of the high SNR of T1 weighted sequences while measuring the Gd-induced phase shift and T2*. Finally, we discuss the implication of this work on the use of new contrast mechanisms for MRA.

MATERIAL AND METHODS

Susceptibility mapping MRA conditions were simulated on a 1.5T scanner (GE signa) using a curved tube phantom with steady water flow (15mL/s), diameter d = 8 mm, and radius of curvature R=62.5 mm (Fig. 1). Several Gd-DTPA (Magnevist) solutions with concentration [Gd] = 0, 8.3, 16.6, 25.0, and 33.3 mmol/L were injected into the tube for 20 sec at 1 mL/s and immediately flushed with water for 30 sec. During the injection protocol, a 2D spoiled gradient-echo interleaved dual-echo sequence was played out to acquire a coronal slice encompassing the phantom. The following imaging parameters were used: 26 phases, 20mm thickness, FOV=30×15 cm, BW=±62.5kHz, matrix size 256×128, TR/TE1/TE2=8.6/2.1/6.1ms, α=40°, and a standard extremity coil for RF transmission and reception.

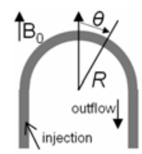

Fig. 1. Phantom.

Phase shift: The reference phase map was determined by summing the final 6 images of the dynamic set, after the Gd was flushed from the phantom. The frequency shift was obtained by subtracting the reference phase from the index phase acquired from the image with the largest enhancement. An algorithm was used to register the curved phantom and to calculate the mean frequency shift as a function of θ in 5° increments. Note that only the first echo was necessary to produce the phase map. For this geometry, the ratio of d/R = 0.13 << 1, and a cylindrical model for susceptibility difference was assumed, producing a frequency shift equal to $\Delta f = 1/2\ [Gd]\ \chi_m f_0 (\sin^2\theta - 1/3)$, where χ_m is the molar susceptibility (3.1×10^{-4} ppm·L/mol from the Curie law T=293K) and f_0 the ^{1}H resonant frequency.

Apparent relaxation: The T2* map was extracted from the ratio of the first and second echo images, assuming exponential signal decay. Dependence of T2* on orientation was evaluated from the mean signal as a function of θ in 5° increments for both echoes.

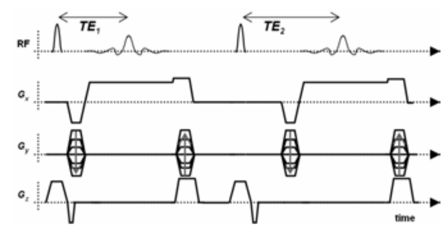

Fig. 2. Dual echo pulse sequence diagram

Orientation dependent excitation A 3D spoiled gradient echo sequence without slice selection was utilized to illustrate the dependence of the resonant frequency of Gd doped water on its geometrical orientation. An asymmetric hamming-filtered sinc pulse with one side lobe, BW=300Hz, and 10ms duration was used for RF excitation. 16 images were acquired with [Gd] = 35.7mmol/L. Shimming was previously done on a large pure water phantom. Scan parameters were the same as those above, with TE/TR=4.2/17.2ms, and 10mm thickness.

RESULTS

Susceptibility mapping The frequency shift and T2* induced by Gd appear to depend on orientation (Fig. 3, 4). Further, the mean frequency shift fits closely to that predicted by the infinite cylinder model (observed for all [Gd]). The mean frequency shift within the phantom increased linearly with [Gd], as expected (Fig. 5). T2* was minimum when the tube was orientated perpendicular to B_0 (Fig. 3b). T2* decreased with [Gd], as for its angular dispersion (Fig. 5).

Orientation dependent excitation The feasibility of selectively exciting materials as a function of geometry is demonstrated in Fig. 6.

DISCUSSION AND CONCLUSION

Susceptibility effects induced by Gd in a vascular-like geometry successfully fit the frequency variation calculated for a cylindrical model. The spoiled gradient echo sequence provided a simple and fast way to map frequency changes while simultaneously taking advantage of the T1 enhancement obtained with CA. For a typical [Gd]=10 mmol/L (2%), the frequency shift is within 100Hz, which may result in a chemical shift-like artifact. Although here a reference phase was acquired to accurately measure the phase shift induced by the CA, a single echo acquisition could be used for the same purpose with an adequate algorithm to correct for background phase variation. Here we used dual echoes to show that susceptibility also changes T2*. For 2% Gd, the mean T2* was approximately 14ms and dependent on orientation (6ms variation over 90°) which may adversely affect image contrast in current clinical practice. T2* dispersion as a function of orientation decreases with an increase in [Gd], which may be useful for proposed methods to map the direction of vascular structures [8]. We showed that frequency shift can be used to determine structure orientation and proposed two methods, frequency mapping and selective excitation to take advantage of susceptibility mechanisms for MRA.

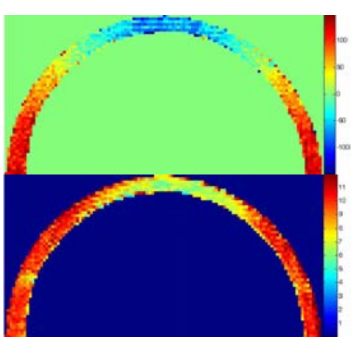

Fig. 3. Frequency shift in Hz (top) and T2* in ms (bottom) maps with [Gd] = 16.6mmol/L.

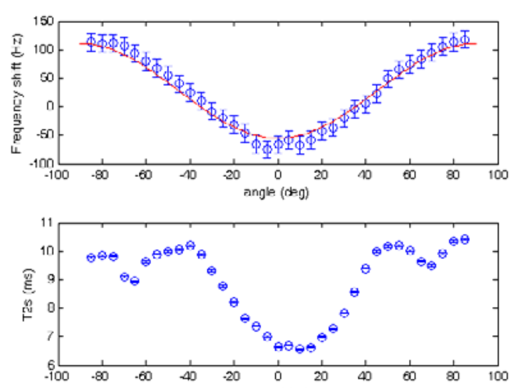

Fig 4. Predicted (red) and experimental (blue) angular dependency of mean frequency shift (top) and T2* (bottom) with [Gd] = 16.6mmol/L.

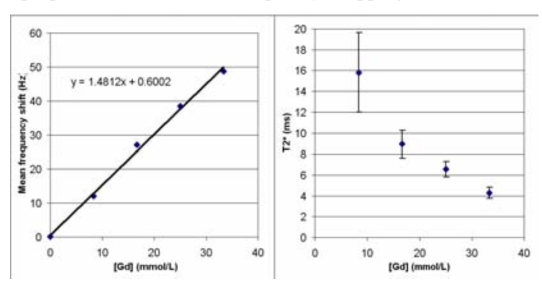

Fig 5. Mean frequency shift and T2*

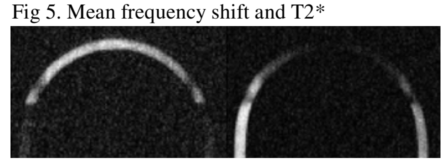

Fig 6. Orientation dependent excitation. Frequency was increased by 400Hz between left and right images.