In Vivo Conductivity Measurement using MRI based Noise Tomography at 3T

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Introduction

In fast MRI methods such as parallel imaging, data acquisition time is decreased by purposely undersampling in the phase encode direction. Instead, spatial information encoded in the NMR signal received by elements of a phased array is used to unwrap the Nyquist folded image. Recently, it was shown that additional spatial information is also encoded in the noise signal received by the array, which is proportional to the conductivity distribution of the sample [1]. At high frequency, sample noise is more dominant than at low frequency, therefore array elements have increased sensitivity to changes in conductivity. In this paper, the conductivity distribution is measured using an MRI based Noise Tomography (NT) technique at 3T (123.3 MHz), using calibrations and numerically calculated fields from either FDTD or quasistatic simulations corrected for the finite speed of light.

Theory/Experiment

The correlation (N_{ij}) of Johnson noise signal received from coil array elements i and j of M receive coils is given by,

$N_{ij} = \int_{t=0}^{T} \langle n_i n_j \rangle dt \approx \int_{sample} \sigma(\bar{r})\bar{E}_i(\bar{r}) \cdot \bar{E}_j(\bar{r}) dV = \sum_k A_{ijk}\sigma_k$ (**Eq. 1**), where E_i and E_j are the unit current oscillating electric fields in the phantom from the i^{th} and j^{th} coils and σ is the conductivity distribution of the phantom. The term on the right describes the case where there are a known number of objects, indexed by k, each assumed to have a uniform conductivity. If there are enough array elements, hence noise correlations, and an accurate simulation of the electric fields from each of the coils, Eq.1 can be inverted to find the conductivity distribution of a phantom. In this simulation based NT method, either a fullwave simulation must be done or, alternatively, a quasistatic could be used. For quasistatic simulations, two corrections must be made. The first is to include a phase correction to account for the finite speed of light. The second is to include correlated noise induced from conductor noise from other array elements. This is done by modifying Eq.1 to give,

$N_{ij} \approx \int_{sample\,and\;conductors} \sigma(\bar{r})\bar{E}_i(\bar{r}) \cdot \bar{E}_j(\bar{r}) \cos\left((2\pi f \sqrt{\varepsilon}/c)\left(\left|\bar{r}-\bar{r}_j\right| - \left|\bar{r}-\bar{r}_i\right|\right)\right) dV$ (**Eq. 2**), where r_i and r_j are the locations of the i^{th} and j^{th} coils and ε is the permittivity of the phantom. Full wave FDTD as well as corrected quasistatic 3T simulations were performed, using an array of eight coils built onto a phantom with a removable tube filled with different concentrations of saline as seen in *Fig. 1a*. As part of a calibration, the 28 different noise correlations were measured while the saline concentration of the removable tube was varied from 0g/L NaCl (ie distilled water) to 40g/L. These noise correlations were determined from individual channel noise images with 5 averages of a matrix of 1024^2 points and R_x bandwidth of 350Hz/pixel. A second, non-simulation based method was tested, using all the calibration data, and two test points, at 20g/L and 34g/L. Although a linear dependence of noise correlation vs. conductivity is expected, both linear and polynomial fitting methods were used to determine the noise correlation versus conductivity sensitivity mapping (*Fig.1d*). Then a sensitivity weighted minimum least squares technique was used to determine the "unknown" conductivity of the two test points (*Fig.1e*).

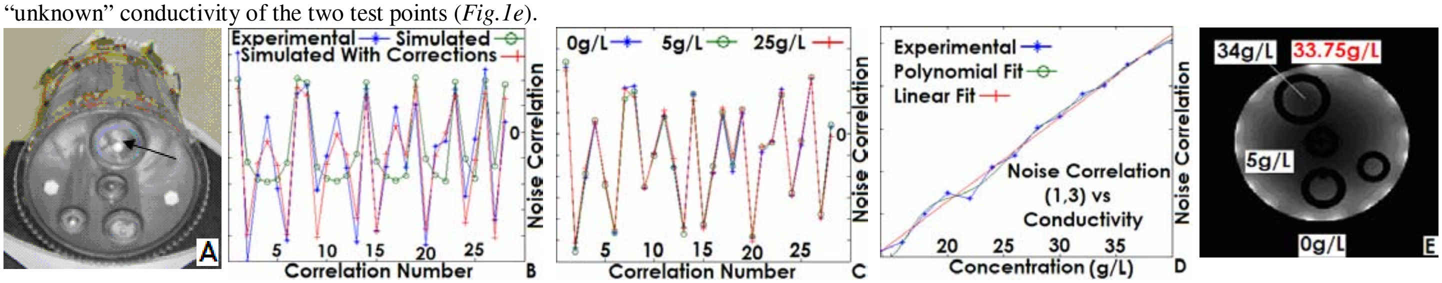

Fig. 1: (**a**) NT phantom and phased array setup, arrow points to removable tube; (**b**) 28 experimental and simulated noise correlations. The simulated noise correlations are done with and without the phase and conductor noise corrections; (**c**) Experimental noise correlations for the tube filled with three different concentrations of saline; (**d**) Experimental noise correlation (1,3) as a function of conductivity, fitted to straight line and polynomial curves; (**e**) Conductivity map using non-simulation based NT method for the case where the conductivity was measured to be 33.75g/L

Results

When linear sensitivity fitting and an un-weighted minimum least squares (MLS) technique was used to calculate the concentrations of the removable tube for the two test cases, concentrations of 21.13g/L and 34.72g/L were calculated. When the sensitivity weighted MLS method was used, concentrations of 20.88g/L and 34.54g/L were calculated. Finally, with polynomial sensitivity fitting, and a weighted MLS solution, 20.22g/L and 33.75g/L were calculated for the unknown conductivities, showing excellent agreement to the test point concentrations of 20.0g/L ± 0.5 g/L and 34.0g/L ± 0.6 g/L.

Discussion/Conclusions

It was deterimed that a 3T simulation based NT method has difficulty accurately measuring conductivity because the sensivity of noise correlations to changes in conductivity are very low (*Fig.1c*), well below the uncertainty in the corrected quasitstatic or full wave simulations (*Fig.1b*). On the other hand, the fully calibrated, non-simulation based NT method was able to accurately measure an "unknown" conductivity within 0.25 g/L or 1% of the nominal value. One could imagine several applications where a non-simulation, fully calibrated NT technique could be used to locate and measure the conductivity of objects within the load of an RF receive array system.

References: [1] Duensing, US Patent #6865494

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