Inductively Coupled Reference Signal Injection Method for Quantitative MRI

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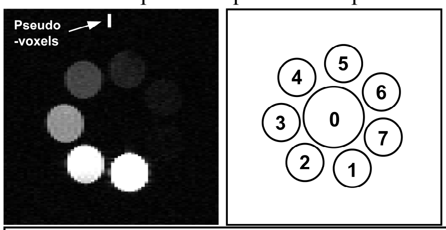
Introduction

We previously described a synthetic signal injection method for MR spectroscopy that addresses some of the problems, such as variable coil loading conditions and receiver gain stability, associated with determining the conversion factor (1). Our method uses mutual inductance (or shared magnetic field) that allows the pseudo-FID to be transmitted by the injection coil and received by the main RF coil so that it is acquired and processed under the same conditions as the real FIDs. In this study, we have adapted the synthetic signal injection method for use in ^{19}F image quantification.

Methods

MRI was conducted on a Bruker 4.7 T horizontal bore magnet equipped with Varian INOVA spectrometer. A custom-built ^{19}F saddle coil was used for transmitting and receiving ^{19}F signals and for receiving injected reference signals. The injected reference signal at the ^{19}F frequency (here 188.6 MHz at 4.7 T) were also transmitted via an injector coil (1.5 mm diameter surface coil mounted on the main RF coil) during (Fig.1) or separately (Fig.2.) from the acquisition of real images. Sodium fluoride (NaF) solution (starting ^{19}F concentration of 0.8 M) was diluted to prepare 6 additional concentrations of 0.4, 0.2, 0.1, 0.05, 0.025 and 0.0125 M. Conventional spin echo imaging sequence was modified to incorporate the signal injection method and to create pseudo-voxels. Coil loading condition was altered by changing NaCl concentrations (0, 0.2 and 2 M) in distilled water filled in a 10 cc syringe. The middle cartoon in Fig. 1 shows the sample configuration: 7 vials filled with NaF solutions of different ^{19}F concentrations and the 10 cc syringe located at the center of the circled NaF vials. A calibration sample was prepared in a 5 cm i.d. plastic bottle filled with 0.2 M NaF solution for separate acquisitions of pseudo-voxel images as shown in Fig.2.



Number	^{19}F (M)
0	0
1	0.8
2	0.4
3	0.2
4	0.1
5	0.05
6	0.025
7	0.0125

Figure 1. ^{19}F image of NaF samples in different concentrations and injected ^{19}F pseudo-voxels. TR/TE=10s/13ms, number of averaging of 4, slice thickness of 8 mm, field of view of 60 x 60 mm^2. NaF sample configuration is shown in the middle cartoon. Seven 19F concentrations (from 1 to 7) were prepared as shown in the table. Ten *ml* syringe filled with distilled water containing different NaCl concentration (sample 0, no fluorine) was located at the center of the group of the seven sample vials filled with NaF solutions. Salt concentrations in sample 0 were varied with 0, 0.2 and 2 M to induce different coil loading conditions.

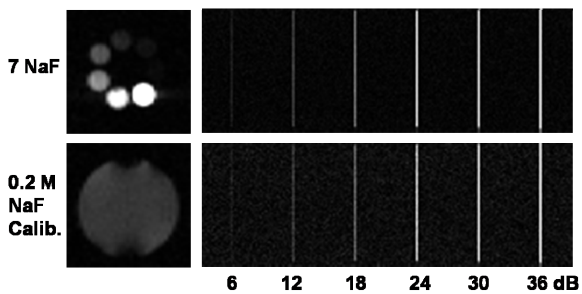


Figure 2. Separate acquisitions of pseudo-voxels with different input powers ranging from 6 to 36 dB. Real image for 7 NaF vials were acquired and its corresponding pseudo-voxel images were subsequently obtained. A calibration sample of 0.2 M NaF was imaged under the same experimental conditions to those for real image to take account of RF field inhomogeneity within a saddle coil.

Results

Figure 1 shows ^{19}F image of 7 NaF samples and the injected pseudo-voxels. Detailed information of the images is provided in the figure caption. Both real and pseudo voxels were acquired at the same session (see Fig. 1) and at two different acquisitions separately for the two signals (see Fig. 2). Figure 3 shows the simultaneous acquisition of pseudo-voxels with that of real image and the correlation between the known concentrations and calculated concentrations for sodium fluoride using signal intensity measured for 0.8 M NaF phantom. The image intensity can be accurately converted to units of concentration. The calculated concentrations for both the simultaneous and separate acquisitions of pseudo-voxels fall along the line of identity (correlation coefficient = 0.95), validating that the conversion from image intensity to concentration is accurate and immune to coil loading conditions. The real signal and pseudo-signal are affected equally by changes in coil loading.

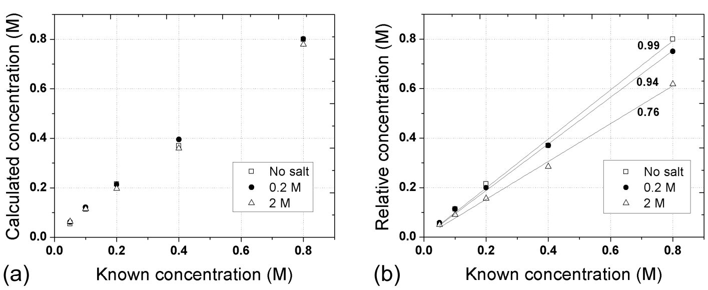


Figure 3. (a) The graph shows the correlation between known concentrations and the concentrations calculated based on our method. In comparison, the relative concentrations, or uncorrected concentrations, (b) reflect a substantial drop in signal as the loading of the coil increased. The relative amplitudes acquired with no salt in the loading syringe were about 25% higher than they were at the highest salt concentration. Relative concentrations generate the slopes of 0.99 ± 0.02, 0.94 ± 0.01 and 0.76 ± 0.02 for the loading samples of 0, 0.2 and 2 M NaCl, respectively.

Discussion and Conclusions

We demonstrated that our reference signal injection method can be implemented for ^{19}F MRI quantification. The image intensities measured from ^{19}F images were accurately converted to units of concentration. The quantification process using this method was immune to changes in RF coil loading conditions. Pseudo-voxels can be introduced before or after real image acquisitions to generate pseudo images instead of simultaneously acquiring both pseudo and real images. The separate acquisitions could allow more flexibility of the synthetic signal injection method including signal-to-noise ratio improvement of pseudo-voxels by increasing the number of voxels on a pseudo image. Our robust quantification method is not limited to ^{19}F MRI but is rather applicable to MR quantification for any MR visible nuclei.

References

1. K. Marro, D. Lee et al. Synthetic signal injection using inductive coupling. *J Magn Reson* **194**, 67-75 (2008).

Acknowledgements

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