Pseudo-signal injection via inductive coupling creates a calibration factor for metabolite quantification that is immune to coil loading conditions

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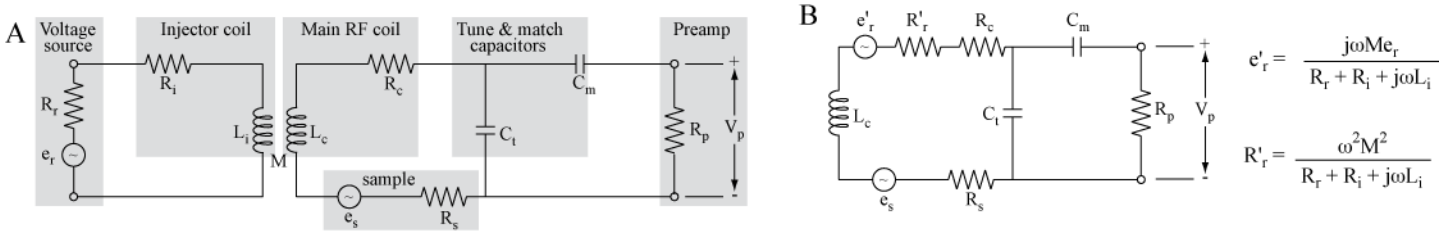
Introduction

Despite the proportionality between the local magnetic field (B_{1m}) generated by excited nuclei within a measurement volume and the integrated area of the corresponding peak in the processed spectrum, most MR results are reported in arbitrary units or in terms of ratios. This situation persists because the proportionality depends on a number of factors, some of which are difficult to assess or control. One way to ease the burden of converting MR spectra into units of metabolite content is to inject a calibrated, artificial reference signal (a pseudo-signal) during acquisition of the real signal. Pseudo-signal injection can be accomplished using a broad band antenna [1] but this method is limited to small animals and in vitro studies because the amplitude of the received signal, and hence the calibration factor, is affected by objects in the vicinity of the antenna and RF coil, including the sample itself. A promising alternative is to create the pseudo-signal using an inductively coupled injection coil [2]. In this study we demonstrate that both B_{1m} and a properly designed injector coil act as voltage sources on the main RF coil. Since the coupling mechanisms are the same, the real and pseudo-signals are affected equally by subsequent data manipulations—including receiver coil sensitivity and loading conditions, amplifier gain and data processing algorithms—making the calibration factor immune to changes in these parameters.

Methods

Measurements were conducted on a 4.7 T Bruker magnet equipped with a Varian Inova console running VNMR version 6.1. The general protocol for quantification of metabolite content with this approach is to conduct a preliminary calibration measurement in which the amplitude and line width of the pseudo-signal are set in proportion to a real peak generated by a sample with a known concentration. The same pseudo-signal is then injected during acquisition of in vivo data for use as a calibration factor. The pseudo-signal was generated by the second RF synthesizer acting as a constant voltage source, e_r, and passed through an external attenuator, R_r, before being fed to the 1.5 mm diameter, two-turn injector coil (Fig 1). The injector coil was fixed in position orthogonal to and in close proximity to a 2 cm diameter, transmit/receive surface coil. The injector and main RF coils were fixed in size and position, relative to each other, so the mutual inductance, M, between them was constant. The orientation and small size of the injector coil ensured that it did not couple with the sample. B_{1m} from the sample acted as a voltage source, e_s. The sample also added resistance, R_s, to the main RF coil. R_s and the tuning and matching capacitors are sample dependent variables because, when the sample changes, R_s generally changes and C_t, and C_m must be adjusted. The detected signal is the voltage, V_p, across a resistor, R_p, in the preamplifier. In Fig 1B, the voltage source and the injector coil have been replaced with an equivalent voltage source, e'_r, and resistor, R'_r, neither of which contain sample dependent variables.

Figure 1



By summing voltages around the loops, the circuit in Fig 1B can be solved for the detected signal, V_p:

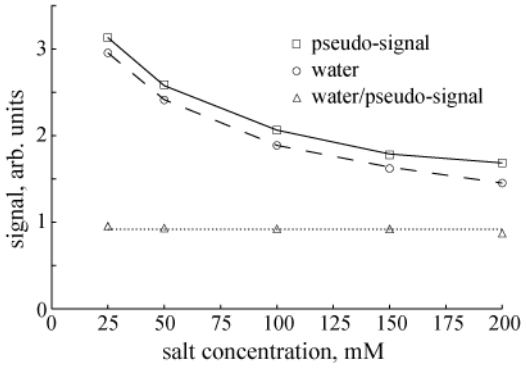
$$V_p = R_p\left\{\frac{e_s + e'_r}{D}\right\} \qquad D = \left\{1 + \frac{C_t}{C_m} + j\omega C_t R_p\right\}\left\{R_s + R'_r + R_c + j\omega L_c + \frac{1}{j\omega C_t}\right\} - \frac{1}{j\omega C_t}$$

V_p can be separated into two components, $V_s = e_s R_p/D$ and $V_r = e'_r R_p/D$. The calibration factor is the ratio, $V_s/V_r = e_s/e'_r$, and it is independent of the parameters that affect coil loading, R_s, C_t and C_m, so once it is set relative to a known concentration, it remains constant.

Results

In vitro experiments (Fig 2) verified that the calibration factor is immune to large changes in coil loading conditions. Increasing salt (NaCl) concentrations dropped the Q of the main RF coil from 570 to 140, reflecting increases in R_s. As Q decreased, the water signal decreased by more than 50% but the pseudo-signal decreased proportionately so the ratio between the two signals remained essentially constant. A simple pulse-acquire sequence was used with the flip angle optimized for each sample.

Figure 2



Conclusion

Use of a small, inductively coupled coil to inject a pseudo-signal provides a robust calibration factor that can be used to convert the real peaks in MR spectra to units of metabolite concentration. This eases the burden of absolute quantification by making the calibration factor immune to coil loading conditions, changes in amplifier gain and data processing algorithms.

[1] L. Barantin, A. LePape, and S. Akoka, A new method for absolute quantitation of MRS metabolites. Mag. Reson. in Med. 38 (1997) 179-182.

[2] D. Lee, E.G. Shankland, M. Mathis, K.I. Marro, C.E. Amara, C.E. Hayes, and M.J. Kushmerick, New synthetic reference signal injection method for absolute quantitation of metabolite concentration. International Society for Magnetic Resonance in Medicine, 15th Scientific Meeting and Exhibition, Berlin, Germany (2007).