Quantitative in vivo magnetic resonance spectroscopy using synthetic signal injection

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Introduction

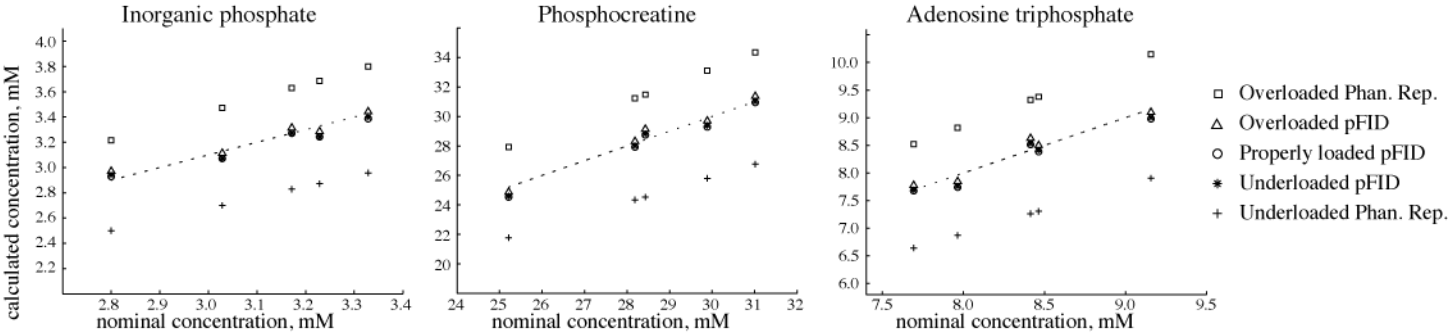
Accurate conversion of MR spectra to quantitative units of concentration generally requires compensation for differences in coil loading conditions, the gains of the various receiver amplifiers, and rescaling that occurs during post-processing manipulations. This can be efficiently achieved by using an antenna to inject a precalibrated, artificial reference signal, or pseudo-signal into the data [1]. We have previously demonstrated, using in vitro measurements, that more robust pseudo-signal injection can be accomplished using a second coil, called the injector coil, properly designed and oriented so that it couples inductively with the receive coil used to acquire the data [2]. In this work, we extend the method to in vivo applications. We acquired nonlocalized ^{31}P-MRS measurements from resting human tibialis anterior muscles and used pseudo-signal injection to calculate the Pi, PCr, and ATP concentrations. We compared these results to parallel estimates of concentrations obtained using the more established phantom replacement method.

Methods

Measurements were conducted on a 4.7 T Bruker magnet with a Varian Inova spectrometer and VNMR version 6.1. Nonlocalized spectra were acquired from tibialis anterior muscles in 5 normal male subjects using a modified version of SPULS, Varian's simple pulse-acquire sequence. Sequence modifications allowed transmission, via a second RF channel, of a pseudo-FID (pFID) to the injector coil during the data acquisition window. Inductive coupling between the injector coil and the 20 mm diameter surface coil used for data acquisition caused a pseudo-peak to appear in the spectra alongside the real in vivo peaks. A long TR (15 sec) and a short delay (< 10 μsec) between signal excitation and acquisition precluded the need to compensate for relaxation effects.

Both the pFID and phantom replacement methods require in vitro calibration measurements. To demonstrate immunity of the pFID measurements to differences in coil loading conditions, calibration data were acquired from three phantoms with different salt (NaCl) concentrations. One contained no salt, and loaded the surface coil less than the in vivo measurements ("underloaded"), one contained 75 mM salt and loaded the surface coil the same as the in vivo measurements ("properly loaded"), and one contained 200 mM salt and loaded the surface coil more than the in vivo measurements ("overloaded"). The metabolite concentrations obtained using the phantom replacement method and the properly loaded calibration data are referred to as the nominal concentrations and were considered the gold standard against which all other results were compared.

Results



Conclusion

The phantom replacement method is frequently used to convert MR spectra to units of concentration, particularly ^{31}P spectra, for which there is no reliable internal reference. A critical constraint for proper implementation is that the calibration phantom and the sample of interest must generate the same load on the RF coil. This is a difficult constraint to meet for human measurements because it requires accurate estimation of the in vivo loading conditions, which can vary widely, and the tedious fabrication of multiple phantoms that replicate them.

Our results demonstrate that the pFID method provides a robust calibration factor that is immune to coil loading conditions and allows accurate noninvasive assessment of metabolite content in humans. The Pi, PCr, and ATP concentrations determined with the pFID method were consistent, in concordance with the nominal concentrations, and fell well within the expected range of normal values. In contrast, the phantom replacement measurements were highly sensitive to coil loading conditions. Immunity to coil loading conditions is perhaps the most important advantage of the pFID approach because it removes a substantial burden and potential source of error that is inherent with other MR quantification methods.

1. Barantin L, LePape A, Akoka S (1997) A new method for absolute quantitation of MRS metabolites. Mag Reson in Med 38: 179-182.
2. Marro KI, Lee D, Shankland EG, Mathis CM, Hayes CE, et al. (2008) Synthetic signal injection using inductive coupling. J Magn Reson 194: 67-75.