Advances in the ERETIC method for the quantification of in-vivo 1H and 31P spectra

S. Schweizer[1], N. De Zanche[1], G. Mens[2], A. Henning[1], and P. Boesiger[1]

[1]Institute for Biomedical Engineering, University and ETH Zürich, Zürich, ZH, Switzerland, [2]Philips Medical Systems, Best, Netherlands

Introduction

Absolute quantification is a desirable tool to precisely determine metabolite changes for clinical diagnostics and physiological studies. While relative quantification is widely used, it has the major disadvantage of ambiguities whenever several metabolite concentrations change simultaneously, as is the case for most diseases. Also, absolute quantification with internal references imposes problems when assessing diseases and when working with other nuclei than ^{1}H. While calibration with ERETIC (Electric REference To access In vivo Concentrations) has been proven to be an accurate method for the assessment of absolute concentration in spectra in vitro[1], only preliminary results have been shown in vivo [2]. Furthermore, previous implementations on clinical scanners did not allow for calibration with ERETIC and simultaneous proton decoupling for SNR enhancement. An ultimate demonstration of the applicability of ERETIC for in vivo ^{1}H and ^{31}P measurements subject to B_1 inhomogeneities and differences in coil loading is also missing. *In this work*, we present a new implementation on a clinical scanner by using an auxiliary low-power transmit channel, thus permitting the simultaneous use of proton decoupling and nuclear Overhauser enhancement (NOE) with the high-power proton RF channel of the system during the acquisition of ^{31}P or^{13}C spectra. Stability of the ERETIC signal is demonstrated. Also, ERETIC was for the first time applied to in-vivo ^{1}H measurements. The comparison of brain ^{1}H MRS quantitation results based on the ERETIC approach is in accordance with literature values obtained by measuring with an external standard [3].

Materials and Methods

The ERETIC RF signal was sent through an auxiliary low-power transmit channel of the system. Signal amplitude, T2 decay, frequency offset relative to the reference frequency (H_2O in ^{1}H MRS, PCr in ^{31}P MRS) and phase offset can be adjusted according to the spectroscopy measurement. For single-voxel MRS, phase cycling can also be applied since the ERETIC signal phase is synchronized with the acquisition. A T/R switch synchronized with the acquisition isolates the ERETIC loop using a PIN diode to minimize RF coupling to the proton body coil during transmission. The loop is positioned behind and grounded to the rear RF mirror of a commercial birdcage coil (Philips Medical Systems, Best, The Netherlands) to avoid geometry-dependent electric-field coupling between the ERETIC loop and the load. This arrangement ensures that the ERETIC signal appears to the coil as a purely magnetic dipole source similarly to the NMR signal (Figure 1).

In-vitro calibration datasets were acquired using the spherical GE standard brain phantom. In vivo spectra were acquired with the same parameters used for calibration, TR/TE=2000/35, NSA=64. The spectra were subsequently processed for quantification using LCModel. For a test of the behavior of the ERETIC signal with different coil load, phantoms with NaCl concentrations ranging from 40 to 160mM were prepared. Signal stability was assessed using a spherical phantom with 20mM NAA in a time series with TR=10s and TE=144ms. 1000 spectra were acquired. To demonstrate the benefits of retaining full use of the two high-power RF channels in combination with the ERETIC calibration, phosphorus spectra were acquired. Spectra with and without proton decoupling and NOE enhancement were recorded using a TR of 5000ms and 64 averages (Figure 4).

Results

As shown in Figure 3 (left), the applied ERETIC signal amplitude scales linearly with loading over the range of physiological sodium concentrations with an R^2 of 0.98. Furthermore it is largely unaffected by cable positioning, thus confirming the absence of parasitic coupling. Also, the stability of the signal is confirmed by the data of Figure 3 (right) for a long-term phantom experiment (2h, 1024 acquisitions). The slope of the ERETIC signal is $7 \cdot 10^{-5}$, the coefficient of variation (CV) is 2.78%, compared to a CV of 2.91% and a slope of $2 \cdot 10^{-4}$ for NAA. This stability enabled ERETIC quantification of in-vivo ^{1}H single voxel brain spectra, which yielded a concentration of 8.1mM NAA, 1.47mM Cho, and 5.74mM Cre for white matter (Figure 2). The measured white matter values correspond to literature values measured with an external standard [3]. For ^{31}P spectroscopy, decoupling and NOE enhancement is readily achieved simultaneously to ERETIC (Figure 4), leading to considerable signal increase of all peaks.

Discussion

We have implemented the ERETIC method on a clinical system using a low-power transmit channel, allowing for an accurate quantification while leaving all other RF channels free. This permits quantitation simultaneously to signal enhancement through proton decoupling for ^{31}P and ^{13}C spectroscopy. This capability is crucial when measuring natural abundance ^{13}C spectra.

The ERETIC quantification values obtained by these first ^{1}H in-vivo spectra proved to be well comparable with metabolite concentrations previously reported in literature.

[1] Barantin, L., et Al., Magnetic Resonance in Medicine 38, 1997
[2] Lee, D., et Al., Proc. Intl. Soc. Mag. Reson. Med 15, 3172, 2007
[3] Keevil, et. Al. Absolute metabolite quantification by in-vivo NMR spectroscopy, Magnetic Resonance Imaging, 16, 1998

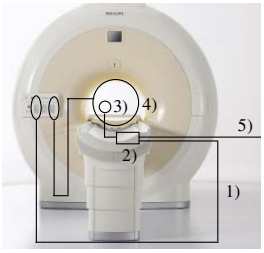

Figure 1
1) T/R signal from scanner
2) T/R switch
3) ERETIC loop behind rear RF mirror
4) T/R head coil
5) ERETIC signal from auxiliary channel

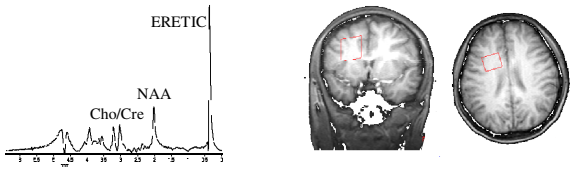

Figure 2: Single voxel spectrum acquired in the white matter of the brain. The ERETIC peak is placed on the right, at 0.4ppm. The spectra were fitted with LCModel; calibration with ERETIC yielded 8.1mM NAA, 1.47mM Cho, and 5.18mM Cre.

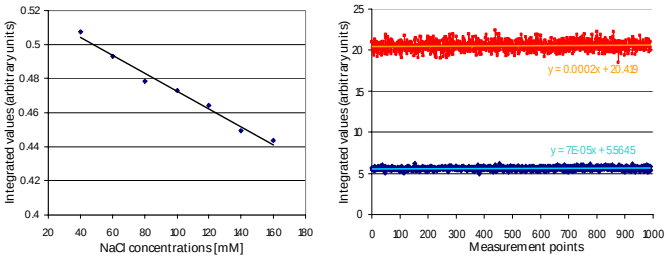

Figure 3: Left: Integrated ERETIC signals at varying loading conditions (40-160mM) show a linear slope (R^2=0.98). Right: Integrated areas of a single voxel time series of a phantom containing NAA. CV for ERETIC peak (blue): 2.78%, CV for the NAA peak(orange): 2.91%

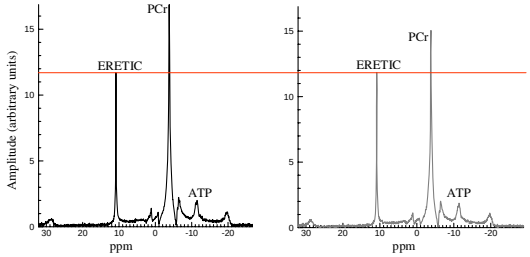

Figure 4: By the use of an auxiliary transmit channel, spectra can be decoupled and NOE enhancement can be made in combination with the ERETIC calibration. In the in-vivo spectrum on the right side, both methods are disabled, while the spectrum on the left side is measured with the same acquisition parameters but NOE and decoupling enabled. The signal enhancement can be easily quantified.