Correction for Artifacts Induced by B0 and B1 Field Inhomogeneities in Chemical Exchange Saturation Transfer (CEST) MRI

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INTRODUCTION Chemical exchange saturation transfer (CEST) imaging provides an indirect detection mechanism that allows quantification of certain labile groups unobservable using conventional MRI. However, CEST contrast is often only a few percent, and therefore, it is important to optimize experimental conditions for reliable and quantitative CEST imaging. In particular, CEST imaging is sensitive to B_0 and B_1 field, while on the other hand; field inhomogeneities persist despite recent advances in magnet technologies, especially for in vivo imaging at high fields. Consequently, correction algorithms that can compensate for field inhomogeneity-induced measurement errors in CEST imaging might be very useful. In fact, such development is crucial for translating CEST imaging to clinic, where field inhomogeneity induced artifacts can be corrected during post-processing, without prolonging the scan time. In this study, we first use 2-pool exchange model and derived the CEST contrast dependence upon B_0 and B_1 field, and proposed a fast correction algorithm. It was verified with both numerical simulation and experimental measurement from a tissue-like pH phantom.

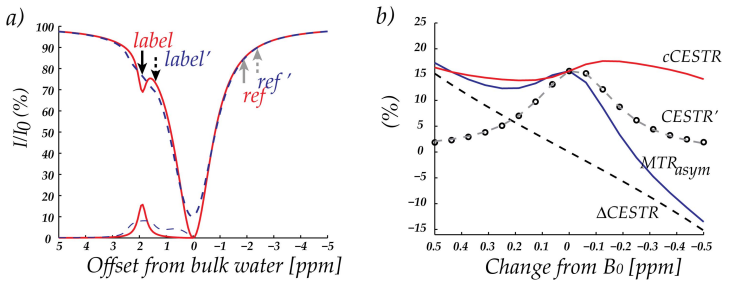

Fig. 1 a) The simulated Z-spectra without (red) and with B_0 inhomogeneity. B) the proposed correction algorithm, that decompose the CESTR into MTR_{asym}, an field inhomogeneity induced offset, and modulation factor. The fully compensated cCESTR shows nearly constant across a range of B_0 field inhomogeneity.

THEORY For the case of a long CW RF irradiation, the CEST ratio (CESTR) is given as, $CESTR = k_{ws} / r_{1w} \cdot \alpha \cdot (1-\sigma)$.

where α is the labeling coefficient, σ is the spillover factor, t_{irad} is the RF irradiation duration, $k_{sw,ws}$ are the chemical exchange rates from labile proton to bulk water and vice versa, with $r_{1w,s}=R_{1w,s}+k_{ws,sw}$, $r_{2w,s}=R_{2w,s}+k_{ws,sw}$, in which $R_{1w,s}$ and $R_{2w,s}$ are the intrinsic longitudinal and transverse relaxation rates of bulk water and labile groups, respectively. In the presence of B_0 field inhomogeneity, the MTR asymmetry analysis will introduce a CEST offset, given as,

$$\Delta CESTR = \frac{4\Delta\omega_S\omega_1^2 T_{1W} T_{2W}^3 \Delta\omega}{\left(1+\Delta\omega_{ref}^2 T_{2W}^2 + \omega_1^2 T_{1W} T_{2W}\right)\left(1+\Delta\omega_{label}^2 T_{2W}^2 + \omega_1^2 T_{1W} T_{2W}\right)}$$

In addition, the saturation coefficient is altered, which can be described by a modulation factors

$$\eta = \frac{\alpha(B_1, \Delta\omega_s)\cdot(1-\sigma(B_1, \Delta\omega_s))}{\alpha(B_1, \Delta\omega_s+\Delta\omega)\cdot(1-\sigma(B_1, \Delta\omega_s+\Delta\omega))}$$

Thus, with the CEST offset and modulation factor known, the CESTR can be shown to be, $CESTR = \eta \cdot CESTR' = \eta \cdot (MTR_{asyn} - \Delta CESTR)$

MATERIASL AND METHODS A falcon tube filled with 3% Agarose and 50mM Creatine was prepared for MRI at 9.4T. In addition, a dual-pH gel phantom of Creatine (60 mM) was prepared with the inner and exterior compartment pH titrated to 5.6 and 6.6, respectively.

RESULTS A simulated z-spectrum (red line) is shown in Fig 1a. The MTR_{asym} was symmetric around the labile proton frequency (1.9 ppm), with its peak intensity being 16.6%. In the presence of B_0 inhomogeneity, the z-spectrum and asymmetry curve showed significant error (dashed line, Fig. 1a). For instance, for a B_0 field error of 0.5 ppm, the 'label' and 'reference' scan will be applied at 1.4 ppm and -2.4 ppm, respectively, rather than at the ideal label and reference frequencies, namely ± 1.9 ppm. Fig. 1b shows that there is a large deviation of MTR_{asym} from PTR if B_0 inhomogeneity is neglected. For instance, at a B_0 offset of -0.5 ppm, MTR_{asym} is actually negative, being -13.5%. It increased with B_0 homogeneity up to 16.6% at 0 ppm (i.e., homogeneous B_0 field). The gray dashed line represents the CESTR offset (ΔCESTR) caused by the asymmetry analysis of mismatched label and reference scans. In fact, the derived CESTR' showed excellent agreement with the simulated CESTR' (circles) without B_0 error. Moreover, by accounting for the modulation factor of the labeling coefficient and spillover factor, the compensated PTR is equal to 15.6 ± 1.3 % (red solid line)

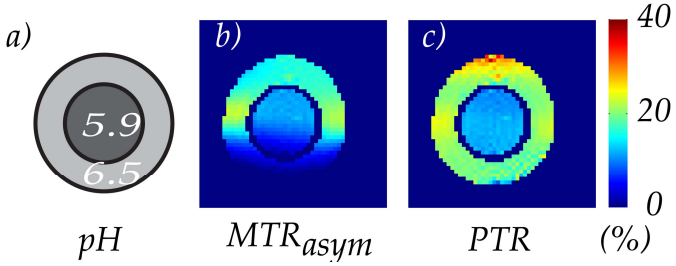

Fig. 2) Illustration of the dual pH phantom, the MTR_{asym} prior to B_0 field inhomogeneity correction and the fully compensated CEST map using the proposed algorithm.

The proposed correction algorithm was evaluated using a dual tissue-like pH phantom (Fig. 2). Under homogeneous field, the measured MTR_{asym} is 12.3±0.8% and 21.8±1.1% for pH of 5.9 and 6.5, respectively, corresponding to a CEST contrast of 9.5%. After adjusting the shimming gradient, the B_0 field mapping was measured to be -13±34 Hz and -5±81 Hz and the MTR_{asym} decreased to 9.2 ± 3% and 11.9 ± 8% for pH of 5.9 and 6.5, respectively. The pH induced CEST contrast decreased to 2.7%. Using the proposed correction algorithm, the CESTR of the inner and outer tubes were compensated to be 11.7 ± 0.9% and 21.7 ± 2.8%, respectively, with the corresponding CEST contrast being 10%, significantly higher than that prior to correction (2.7%) and in very good agreement with that derived with homogeneous B_0 field (9.5%).

REFERENCES 1)Zhang S et al, JACS 2003; 2)Aime S et al, MRM 2003; 3)Zhou J et al. Nat Med. 2003. 3)Sun PZ et al. MRM 2007. 4)Sun PZ et al. JCBFM 2007.