A New Method for Fast Quantitative Mapping of Absolute Water Concentration in vivo

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INTRODUCTION

Many pathological conditions are accompanied by a local or global increase in water content. Common diseases of the human brain with a high prevalence such as stoke and brain tumours are often associated with oedema of varying extent [1]. Several methods for water content mapping with MRI have been published in the literature. They all suffer from specific limitation such as being not really quantitative [2], requiring long measurement times [3] or not including all relevant correction factors that are necessary for a high precision measurement [4]. We present a method for the quantitative measurement of localised, absolute water content based on the combination of two recently developed methods for T_2^* and T_1 mapping sequence, QUTE-EPI [5] and TAPIR [6-9]. Incorporation of all relevant correction factors allows the determination of water content with good anatomical resolution. The results demonstrate that *in vivo* measurement of regional absolute water content is possible in clinically-relevant measurement times with a statistical and systematic measurement error of <2%.

METHODS

The relaxation times T_1 and T_2^* were measured using the TAPIR and the QUTE-EPI sequences, respectively. To extract the $M_{0,T2*}$ from the T_2^* decay curve in the presence of inhomogeneity sources that cause signal dephasing, the signal intensity was fitted by an polynomial of 3rd order by χ^2 optimisation and extrapolated back to TE=0 to get $M_{0,T2*}$. Polynomial fitting is vital to get an unbiased measurement of $M_{0,T2*}$ in regions of large inhomogeneity where the signal decay deviates significantly from exponential behaviour. An absolute measure of water content $W_{MR,}$ is obtained by placing a reference probe containing 100% water within the FOV during the measurement thereby allowing the parameter $M_{0,T2*}$ (tissue) to be related to $M_{0,T2*}$ (reference). Spatial variations in the B_1 excitation field that cause systematic errors in the study of absolute water content are corrected without any additional measurement using the fact that $M_{0,T2*}$ and $M_{0,T1}$ were acquired with different nominal flip angles of α_{QUTE}=90° and α_{TAPIR}=25° respectively. The effective flip angle α_{eff} for a nominal α_{QUTE} excitation pulse at each voxel can be extracted from $M_{0,T2*}$ and $M_{0,T1}$ by the following relation:

$$\frac{M_{0,T2*}}{M_{0,T1}\cdot C_{T2*Decay}} = \frac{\sin(\alpha_{eff})}{\sin\left(\frac{\alpha_{TAPIR}}{\alpha_{QUTE}}\alpha_{eff}\right)\cdot C_{T1Sat}(\alpha_{eff})}$$

Here, $C_{T2*Decay}$ and $C_{T1Sat}(\alpha_{eff})$ correct for decay and saturation effects of $M_{0,T1}$ and $M_{0,T2*}$ respectively. T_1 saturation effects where corrected based on the TAPIR measurement. The temperature of the reference probe was determined immediately before and after the measurement and M_{0T2*} (reference) was extrapolated from the mean temperature to a body temperature of 37°C by the relation in [10,11]. Phantom measurements were performed using tubes with different mixtures of water (H_2O) and heavy water (D_2O) with volume ratios VR=V(H_2O)/(V(D_2O)+V(H_2O)) between 50% and 99% doped with small amounts of $MnSO_4$ between 0.373mM/L and 0.411mM/L. As D_2O is not MR-visible at the proton frequency, it does not contribute to the observed signal.

RESULTS AND DISCUSSION

Fig. 1a shows the reconstructed quantitative water map of the multi-compartment H_2O/D_2O phantom located at the scanner isocentre. A clear contrast between the tubes is visible which is determined only by differences in water content. Fig 1b shows results for W_{MR} if corrections for flip angle miscalibration $C_{B1Inhom}$ and receiver profile inhomogeneity $C_{receiver}$ are ignored. Ignoring B_1 changes results in an absolute systematic error between –0.3% and +4.3% with a mean of +1.7%. These effects are worse if the receiver profile is not considered properly. The systematic overestimation of absolute water content in this case ranges between +2.1% and +8.3% with a mean error of +5.2%. Fig 2 shows the quantitative water map for a selected slice through the brain of a normal healthy volunteer. Results in Fig 2b were obtained by the procedure described above. In contrast, Fig 2a shows the water map reconstructed by replacing the polynomial fitting procedure for the determination of $M_{0,T2*}$ with a simple exponential fit. A clear overestimation of water content is visible in brain regions near the sinus cavity. In addition, anatomical information is not visible in this area in contrast to the map fitted with the polynomial procedure described.

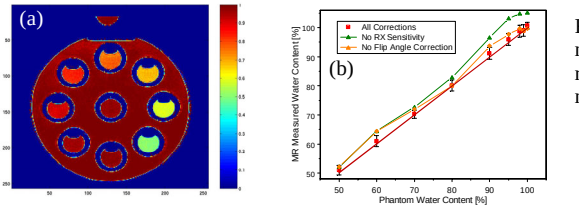

Fig 1: (a) Water map of the multi-compartment phantom consisting of tubes with different H_2O/D_2O mixing ratios. (b) Known phantom water content versus W_{MR} with all corrections applied (red rectangles), no correction for receiver coil inhomogeneity (green line) and no correction for flip angle miscalibration (orange line).

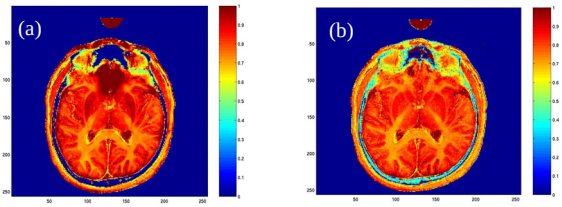

Fig 2: (a) Water content for a transverse slice through the brain of a healthy volunteer with $M_{0,T2*}$ reconstructed by an exponential fit. (b) The same slice but reconstructed with the polynomial fitting procedure as described in the text.

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