Quantitative Water Content Mapping at 1.5 and 3 Tesla Field Strength

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MRI offers the possibility of quantifying tissue water content *in vivo*. The utility of such a technique has been proven in medical research, such as the detection of cerebral oedema in brain diseases [1] and would clearly benefit clinical practice in the form of a routinely applicable protocol. Different methods exist to achieve the quantification of tissue hydration. These include: multi-echo GRE [2], hybrid GRE / TAPIR [3] and IR-SE [4] based methods. In this work, a 2-D fast gradient echo approach is developed for a 1.5T and a 3T system, extending a previously developed method [2]. The attractiveness of this approach is due mainly to its ability to detect water pools exhibiting short relaxation times, such as myelin water [5]. However, it is known that gradient echo sequences are highly sensitive to B_0 non-uniformities. In this regard, the method needs to be improved in order to prevent possible inaccuracies, especially in regions located in the vicinity of air-tissue interfaces. In particular, for this reason, a 1-litre water cushion is used in place of a 50 ml vial, providing a proton density reference of large volume. Furthermore, given that the RF field non-uniformities are significantly more pronounced at 3T, the resulting corrections must be adapted for larger variations. The proposed protocol is suited to clinical use and requires approximately 15 min of scanning time. It is designed either for a receive-only phased array (**PA**) coil (the body coil (**BC**) is then used for excitation) or a quadrature transmit-and-receive (**Tx/Rx**) birdcage coil. In this article, the structure of the protocol and the reconstruction block-diagram are presented and the precision of the water content measurement is discussed. Finally, results obtained at 1.5 and 3T are compared and discussed.

The protocol and the reconstruction of the quantitative maps

The measurement process is based on the QUTE [3] sequence, a multi-echo spoiled GRE sequence (with TR = 2100 ms, FA = 40 deg, 10 echoes, TE_1 = 4.8 ms, ΔTE = 3.53 ms, BW = 300 Hz, T_{acqu} = 7.1 min), depicted as GRE(M_0) in Fig.1. The signal at zero echo time is reconstructed using an appropriate parametric model of the gradient echo decay. A sequence of the same type GRE(T_1) (with TR = 700 ms, FA = 70 deg, T_{acqu} = 2.37 min), is combined with GRE(M_0) to estimate the steady state correction. The protocol proposed in [2] is upgraded by slice profile correction. This resolves the problem of a systematic error in the steady state correction of very similar origin as the bias reported in [6]. In addition to this, the actual flip angle distribution is measured using a series of 2 or more echo planar images (depicted as EPI(Tx, Rx) in Fig.1) with various flip angles. At 3T, 4 angles (30, 60, 90 and 120 deg) are used in order to address an important range of RF variations (40% variation expected) whereas only two angles (30 and 90 deg) are sufficient at 1.5T (less than 20% RF variation expected) without loss of accuracy. If the PA head coil is used, the estimation of the receiver non-uniformity is achieved by acquiring a pair of low resolution spoiled GRE sequences (with TR = 1000 ms, FA = 30 deg), depicted as GRE(Rx=BC) and GRE(Rx=PA) in Fig. 1. Otherwise, since the transmit and receive properties of the Tx/Rx birdcage coil are reciprocal, sole knowledge of the flip angle map is sufficient to perform the RF non-uniformity correction. After temperature correction of the signal measured in the water cushion (visible in Fig. 2, under the patient's head) and after calibration, the computed image, M_0, finally represents the estimated water content in percent units [5].

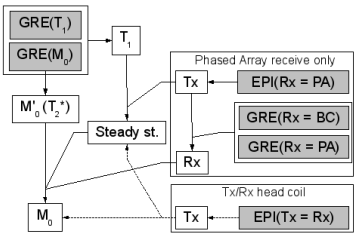

Figure 1: Diagram of the measurement process

Due to possible imperfections of the measurement process, it is a requirement to check the precision of the water content estimation. Phantom experiments based on H_2O/D_2O solutions with controlled proton density [2] were carried out. The precision obtained in this latter experiment at 3T was 2% in both the transmit-and-receive birdcage coil or the phased array head coil and this corresponds to the precision previously reported at 1.5T [2].

Results in vivo at 1.5T and 3T

Cerebral water content maps were acquired at 1.5T and 3T, respectively on a MAGNETOM Avanto and a MAGNETOM Trio system using the protocol presented above. The FOV in plane was 256 x 192 mm and was sampled at 1 mm resolution. 50 slices of thickness 2 mm were acquired in an interleaved mode with 1 mm gap. In Fig. 2, a 1.5T – 3T comparison of *in vivo* data is shown. Fig. 2a) represents a 1.5T water content map in a 33 years old healthy woman, obtained using a PA head coil. Fig. 2b) and 2c) show 3T results obtained respectively with a PA head coil and a Tx/Rx birdcage coil. Fig. 2b) shows results for a 26 years old healthy woman and Fig. 2c) - for a 28 years old healthy man. As expected, all images reflect comparable water content distributions. Qualitatively, the water content maps obtained at 3T exhibit an improved SNR, especially in Fig. 2b), where the PA head coil was used. Nevertheless, the 3T image obtained with the PA head coil manifests some inaccuracies, mainly in the frontal lobe. These inaccuracies could be due to the proximity of the circuit of the head coil to the frontal lobe. This effect did not occur in the validation phantom experiments, supposedly because the container used is smaller and hence is more distant to the circuits of the head coil.

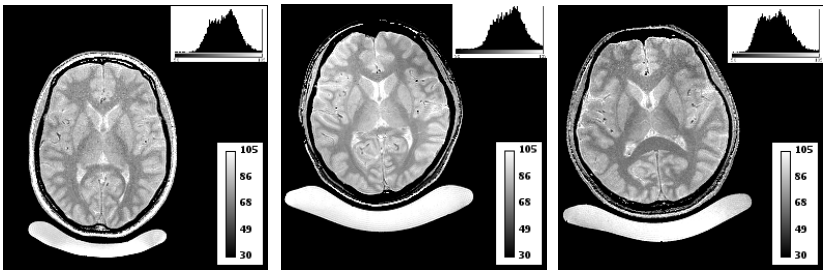

Figure 2: Water content maps in a) a 33 years old healthy woman on Avanto (PA head) b) a 26 years old healthy woman on Trio (PA head) and c) a 28 years old healthy man on Trio (Tx/Rx head)

Conclusion

A 1.5T and 3T quantitative water content imaging protocol is investigated. The expected benefit of working at 3T is a significant gain in SNR. However, static field inhomogeneity as well as RF non-uniformities also grow rapidly with the increasing field strength, eventually causing some loss in accuracy. The protocol and the reconstruction process have been optimised so that the accuracy of the 3T map is well preserved. Using the phase array head coil at 3T, imprecision in the estimated sensitivity map have been detected in regions of the head located in the vicinity of the circuits of the coil. These effects are currently being investigated.

References

[1] Shah et al.: Quantitative cerebral water content mapping in hepatic encephalopathy. *NeuroImage* 41, 706–717, 2008 [2] Neeb et al.: Fast quantitative mapping of absolute water content with full brain coverage. *NeuroImage* 42(3), 1094-1109, 2008 [3] Neeb et al.: A new method for fast quantitative mapping of absolute water content *in vivo*. NeuroImage 31, 1156 – 1168, 2006 [4] Warntjes et al.: Novel Method for Rapid, Simultaneous T1, T2*, and Proton Density Quantification. Magnetic Resonance in Medecine 57, 528-537, 2007 [5] Tofts, P.S., 2003. In: Tofts, Paul (Ed.), Quantitative MRI of the Brain. John Wiley & Sons, Ltd., pp. 85–108 [6] Wu et al.: Actual Flip Angle Imaging: From 3D to 2D. Proc. Intl. Soc. Magn. Reson. Med., 17, 2009.