Optimization Strategies for Relaxation based Myelin Water Imaging: 2. Postprocessing and Signal Correction Techniques

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Introduction: Although the increasing popularity of myelin water imaging (MWI) among noninvasive diagnostic and research tools for better characterization of myelination and neurodegenerative processes led to a series of improvements and alternative developments, a variety of challenges still remain. The most common MWI-technique is based on 2D, MS or 3D multi-spin echo (MSE) T2-relaxation imaging sequences and subsequent numerical inversion to derive a T2-distribution [1,6]. Therefore it is of general interest not only for MWI but also for other emerging multi-exponential quantitative T2-applications (tumour characterization, fat-water composition of body tissue, quantitative assessment of macromolecular tissue like muscle and cartilage) to eliminate those flaws or introduce improvements for better and more stable quantitative estimates of not only the myelin water signal but all components in the T2-distribution. The advantage of MSE-techniques to derive this information is its fair ease of implementation, the well understood MR-physics background and a reliable mathematical handle to solve the ill-posed problem of multi-exponential decaying systems in a robust numerical manner compared to alternative methods (e.g. SSFP).
Apart from usual long acquisition times, major challenges remain in the area of T2-inversion and general echo-decay signal correction, for example the elimination of spurious signals from the T2-echo decay curve arising from stimulated echoes, noise-baseline offsets that are inherited from commonly dealing with modulus image data and a robust time characterization of the T2-distribution ("where are what type of peaks"). For each of these listed problems improvements and alternatives are suggested.

Methods/Results:
1. Where is the myelin peak?: As can be seen from fig.1a, the multi-T2 histogram over an entire slice of the brain reveals no distinct and sharply separated peaks for the myelin-water (MW, <40ms), the intra-extra cellular water (IE, 40<T2<200ms) and the cerebrospinal fluid signal (CSF>1500ms) that are commonly expected from a 3 compartment model of CNS. Width and position of individual T2-peaks depend on SNR, echo sampling and T2-amplitude distribution. A common practical approach usually divides the T2-distribution spectrum into three distinct compartments: MW=10-40ms, IE=50-200ms, CSF>1500ms [2]. In reality, local variations in B1, physiological noise and spatially dependent transmitter/receiver properties will spatially modulate the intrinsic SNR and amplitude-to-noise (ATN) over the decay curve. This causes variations in T2-peak position and -width during the T2-inversion process. An example for mono-exponential behaviour with different SNR is shown in fig.1b,c. The static approach of a fixed integration window for an entire data set (usually 10-40ms) to calculate the myelin water fraction (MWF) will introduce subsequent errors based on the width of the IE main-peak which leads to an artificially high MWF ("main-peak bleeding"). A similar scenario can shift the MW-peak to larger values than 40ms and/or superposition with the IE-peak that will eliminate its contribution from the calculation of MWF. Therefore we introduce an alternative approach by which the integration window is dynamically determined for each individual echo-decay curve by analysing the shape of the T2-spectrum and defining robust cut-off criteria for the upper myelin-integration window. Some exemplary results for improved MW-maps are shown in fig.1d.
2. B1-EPG stimulated echo correction: The idea of using the concept of the extended phase graph [3] to correct for stimulated echoes in a T2-decay curve for MWI was first introduced by [4]. A slice excitation profile correction as recently implemented by [5] is negligible for our 3D-TSE and 3D-GRASE approach due to much better profile characteristics in a 3D-excitation [6,7]. The algorithm was implemented in a multi-core compiled user extension (XOP) using IGOR-Pro (WaveMetrics Inc., Lake Oswego, OR) and is able to process 10 slices with a 256x256 matrix in less than 2 hours. Example of the calculated refocusing-angle (B1) and myelin-maps with and without EPG-correction are presented in fig.2b.
3. Re-phasing of complex data: This methods is based on complex data acquisition of the T2-spin echo signal and subsequent phase correction of each spin-echo for the elimination of Rice-noise offsets in the echo-decay baseline. This approach removes the sometimes over-present "baseline offset artifact" at large T2-values and leads to a more reliable MWF-characterization particularly in areas where in reality no CSF or long-T2-component are present (T2-signal decays into the physiological noise floor). It also improves the estimation of MWF in areas with low myelin abundance due to the absence of an artificial long-T2 component other than CSF caused by the noise-offset in modulus data.

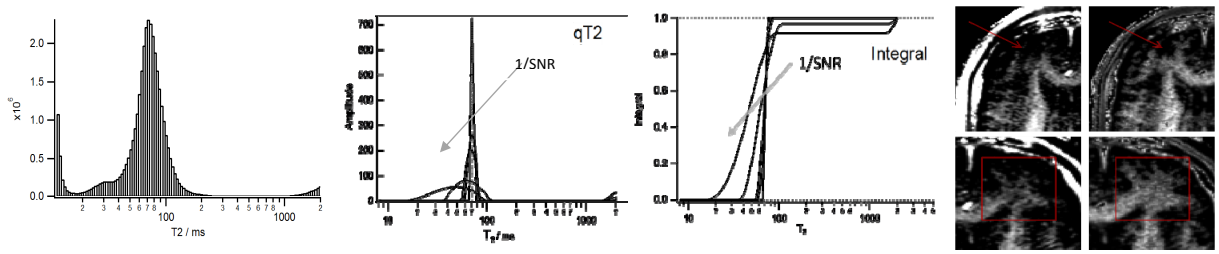

Fig.1: a(left): histogram of all T2-distributions (T2-spectrum) over one entire slice;
b,c (mid); mono-exp. T2-distribution and corresponding integral at various SNR;
d(right): MWF-maps without (left) and with (right) sliding integration

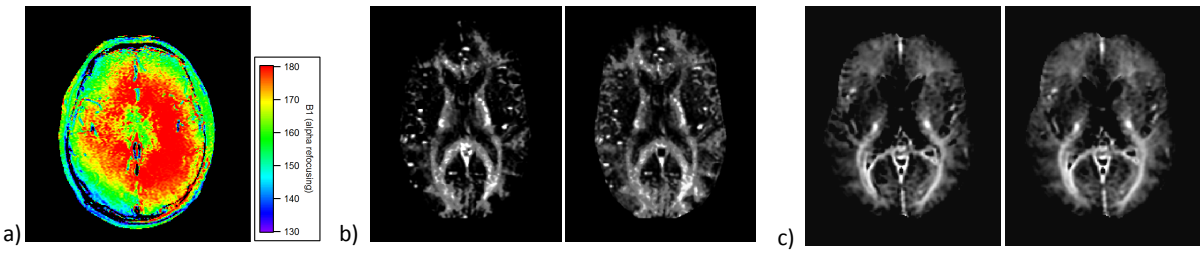

Fig.2: a(left): Refocusing-angle (B1α-map) from EPG-multi-T2-NNLS inversion;
b: B1α-uncorrected and corrected MWI
c: MWI from modulus (left) and rephased complex data (right)

Summary: We show the validity and usefulness of three retrospective correction techniques for multi-spin echo MWI that do not generally require additional data acquisition (except for enabling the storage of complex image data). They lead to substantially more robust estimations of quantitative myelin fraction values even under the presence of moderate to large B1-inhomogeneities inherent to high field MRI systems.

[1] Whittall et al., MRM 37 (1997), 34-43; [2] MacKay et al. MRI 24 (2006), 515-525 ; [3] J. Hennig JMR 78 (1988), 397-407; [4] C. Jones et al. Proc. ISMRM (2003), 1018; [5] RM. Lebel et al. MRM 64 (2010), 1005-1014; [6] B.Mädler et al. Proc.ISMRM 2006; [7] B.Mädler et al. Proc.ISMRM 2007