# T1 based myelin water detection at 3 Tesla using phased-array adaptive reconstruction and long range TI sampling

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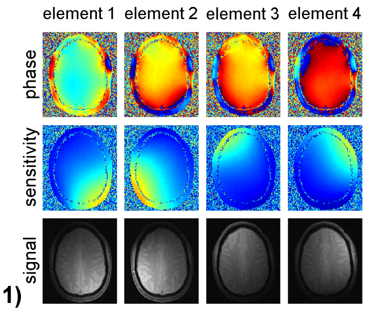
**Target audience –** Neuroscientists interested in measuring the myelin water fraction (MWF) [1] using the real part of a geometrically sampled Look-Locker inversion recovery (IR) acquired with phased-array head coils at 3 T.

**Purpose –** The T1 relaxogram obtained after inverse Laplace transform (ILT) of the real part of a geometrically sampled Look-Locker IR exhibits a small peak below 500 ms attributed to compact myelin water [2]. The detection of a small T1 peak with ILT is challenged by the relative compactness of MR relaxograms, stretching within one or two decade. It is influenced by several factors, including the signal-to-noise ratio (SNR) [3], the estimation of the inversion efficiency [4], and the magnetic field strength [5]. Acquisition with phased-array coils is an attractive technology to improve the SNR obtained with a small excitation flip angle (5°) as required to avoid a perturbation of the IR [6]. In this work we propose a method to coherently combine coil elements from coil sensitivities estimated in place without requiring extra measurements. Additionally we investigate the effect of increasing the range of the geometrically sampled inversion times (TI).

**Methods –** PURR sequence: Following an adiabatic inversion, the IR was sampled with a Look-Locker train of 5°-sinc excitations at 32 TIs geometrically sampled either within a moderate ($TI_1/TI_2/TI_{16}/TI_{32}/TR$=17 ms/33 ms/0.7 sec/8.0 sec/10.5 sec) or long range ($TI_1/TI_2/TI_{16}/TI_{32}/TR$= 38 ms/68 ms/1.54 sec/17 sec/18 sec). An informed volunteer (aged 29, male) was scanned at 3 T (Siemens TIM-Trio) with a 12-channel coil operating in auto-CP mode yielding 4 elements; other parameters TE 7 ms, bandwidth 19.2 kHz, 1.5×1.5×5 $mm^3$, 128×112 matrix. For SNR comparison, six additional volunteers (aged 21-32, 4 women) were scanned with a birdcage (transmit/receive), 12- or 32-channel head coil.
Adaptive combine: Adaptive reconstruction aims at coherently combining coil elements using a complex weighting factor that includes terms for the phase, the noise correlation between coil elements, and coil sensitivities [7]. Unlike other modalities, Look-Locker IR curves can be used to estimate smooth coil sensitivities. The phase was determined voxel-wise for each coil elements by averaging the phase observed at early and late TIs (***Fig. 1 top***, average phase of coil elements of the 12-channel coil operating in auto-CP mode). The IR curves of each coil element were phased and their real part kept (***Fig. 1 bottom***, signal at $TI_{32}$=8 sec). The sum of the phased coil elements was used as a voxel reference IR. The coil sensitivity of an element was determined voxel-wise by computing the average of the ratio of a coil element IR and of the voxel reference IR (***Fig. 1 middle***, smooth coil sensitivities). The coil sensitivities were used as weighting factors to combine phased coil elements.
ILT: The program CONTIN [3] was used to invert the IR curves with 40 T1 grids logarithmically spaced from 80 ms to 7 sec, assuming non-negativity and a regularization encoding smoothness in the image plane of a 5-by-5 sliding neighborhood [8], after estimating the inversion efficiency from an ILT including a linear coefficient (smoothed with a 5-mm FWHM Gaussian filter) [4]. MWF is the ratio of the integral of the small compact myelin water peak below 500 ms and of the total relaxogram integral (***Fig. 2 & 3***). The reported SNR is that obtained from the residuals of the ILT (CONTIN). White (WM) and gray matter (GM) were segmented using the bimodal slice histogram of MWF divided by the long T1 (not shown).



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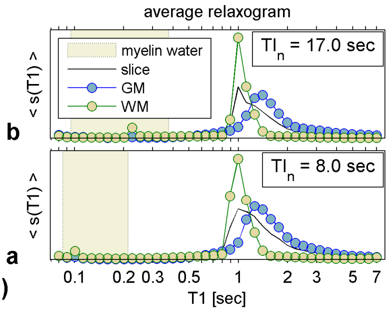

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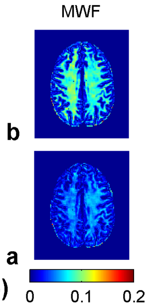

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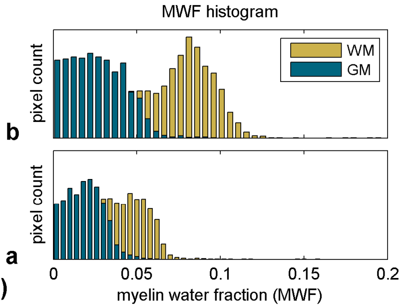

4)

**Results –** An improvement of the SNR was observed with phased-array head coils: in WM, respectively 23.0 ± 1.7 for the birdcage coil (N=3), 32.6 ± 1.8 for the 12-channel coil (N=3), and 40.0 for the 32-channel coil (N=1). ***Fig. 2*** shows the effect of the TI range in one volunteer. The T1 of the small peak attributed to compact myelin water increases with the TI range from 113 ± 9 ms (***Fig. 2a***) to 225 ± 13 ms (***Fig. 2b***) in WM. The MWF follows a similar course. With a moderate range of TI (up to 8 sec), the MWF was 0.050 ± 0.011 in WM, and 0.019 ± 0.011 in GM (***Fig. 3a, 4a***). These values increased with a long range of TI (up to 17 sec): respectively 0.083 ± 0.016 in WM, and 0.026 ± 0.016 in GM (***Fig. 3b, 4b***).

**Discussion –** The SNR of the ILT residuals reveal a significant increase with phased-array coils and suggest a robust adaptive reconstruction with conservation of the phase. Simulations confirmed an effect of the range of TI on the position and intensity of the small compact myelin water peak in the T1 relaxogram (not shown). From these simulations, it may be assumed that the reported MWF at long TI range is approaching the exact value, whereas the exact T1 is underestimated with short TI range and overestimated with long TI range. The MWF values observed at 3 T are lower than those observed with CPMG [1] or at high magnetic field (7 T) [5]. The apparent low MWF at 3 T is attributed to exchange of compact myelin water in combination with the low T1 values of axonal and non-compact myelin water compared to those at higher magnetic field strength [5].

**Conclusion –** With sufficient SNR and a long TI range, it is possible to improve the detection of MWF at 3 T. The proposed method to coherently recombine phased array coils may find applications in other fields such as for the study of magnetic susceptibility of myelin [9].

**References –** [1] MacKay A et al. 2006 *MRI* 24:515. [2] Labadie C et al. 2011 *Proc. ISMRM* p. 230. [3] Provencher SW 1982 *Comp. Phys. Comm.* 27:229. [4] Labadie C et al. 2008 *Proc. ISMRM* p. 1418. [5] Labadie C et al. 2009 *Proc. ISMRM* p. 3211. [6] Labadie C et al. 1994 *JMR* B105:99. [7] Walsh DO et al. 2000 *MRM* 43:682. [8] Labadie C & Jarchow S 2004 *Proc. ISMRM* p. 2707. [9] Wharton S & Bowtell R 2012 *PNAS early view* doi:10.1073/pnas.1211075109.