Preliminary 23Na transverse relaxation time investigation using a continuous distribution model

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Introduction

Changes in sodium compartmentalization in the brain has been shown to be one of the hallmark of neurological diseases. Environment-sensitive 23Na relaxation measurements could provide further insight to modeling disease pathophysiology. 23Na transverse relaxivity in tissue is assumed to be bi-exponential with fixed relative component fractions between a short (0.5-5ms, 60%) and long (15-30ms, 40%) decay [1], due to the energy transitions occurring in different tissue environments [2]. Previously measured 23Na-T2* in the brain of volunteers using a fixed bi-exponential model showed a good reproducibility of the results, albeit it did not show any T2* component much shorter than ~2ms [3].

Here, we analyzed the transverse decay curves obtained in a healthy volunteer using a continuous distribution model based on the regularized inverse Laplace transform, which does not imply a number of exponentials *a priori*. We find that our preliminary results are within the same range of previous reports, but with larger than expected variations in the volume fractions between the short and long components. In addition we observe a very short decay (<1 ms) in approximately 20% of the samples.

Methods & Materials

A fitting routine was based on I.-G. Marino's "Regularized inverse Laplace transform" [4], a Matlab implementation of Provencher's CONTIN program to compute the inverse Laplace transform using a regularized least squares method [5]. 18 echoes between 0.17 ms and 70 ms were acquired on a healthy volunteer's brain using a 3T system (Philips, Netherlands) and a 23Na Rx/Tx volume coil (Rapid Biomed, Germany) using a stack of radials [3] with 5mm nominal isotropic resolution (TR 120, BW 200 Hz/px). A guess distribution g with peaks centered at 2 and 20 ms with 60 and 40 % relative amplitudes respectively, as well as a small amplitude component at 60ms, representing cerebrospinal-fluid (CSF) contamination, was supplied for quicker convergence, over a state space s of 80 points to allow high temporal resolution. A regularizer of 0.01 was used. The fitting procedure was applied to various regions of interest (ROIs). A total of 50 ROIs were drawn in homogeneous white (35) and grey (15) matter on a co-registered proton-density scan.

Results and Discussion

Figure 1 shows an exemplary T2* distribution fit from a WM region, showing increased peak width for the long component, as expected due to the reduced signal-to-noise ratio at longer echo times. In subsequent analyses, only the peak T2*s and amplitudes are used.

Figure 2 shows a bar plot of the estimated short T2* against their estimated amplitudes. Four groups of short T2* can be distinguished of around 0.5, 3, 6 and 9 ms; most frequently around 3 ms for both WM (red) and GM (blue). GM T2* values also show a good cluster around 6 ms. The shortest components, i.e. around 0.5 ms, were found in the occipital WM and GM of the putamen. Amplitudes vary and average short (long) component fractions were 46 ± 18 (43 ± 18) ms for WM and 48 ± 17 (47 ± 23) ms for GM - different from the theoretical 60/40% relationship. This could be due to B0 influences or different sodium environments in different areas of WM and GM. The fitted amplitudes are also dependent on the guess distribution s spacing and the value of the regularizer. Figure 3 shows short T2* components plotted against corresponding long components, with most values falling within a narrow range, suggesting a relatively fixed long T2* component centered around 25ms and short T2* varying more freely between 0 and 8 ms. Outliers due to residual noise background or partial volume with CSF appear away from the main distribution at 95 ms for the long T2*. This is seen in the mean values: WM: T2*(short) = 3 ± 1.7ms and T2*(long) = 27 ± 10ms; GM: T2*(short) = 3.6 ± 2.5ms and T2*(long) = 31 ± 9ms.

Conclusions

In this preliminary study, the continuous distribution fit using the regularized inverse Laplace transform was successfully employed to investigate the transverse relaxation decay of the 23Na-MRI signal confirming its bi-exponential nature in most samples. Very short T2* components were found as well, appearing along the expected long and short components or in bi-exponential fits with two short components. T2*s of ~0.5 ms have been postulated before, but further investigation needs to be performed to confirm this observation and whether there is a relationship between these findings and the anatomical locations. The observed fractions between short and long component vary a lot, this could be due to the regularizer imposed on the fit, as this determines peak width and amplitude, and needs to be addressed in future to confirm the findings. Due to the low gyromagnetic ratio of 23Na, B0 effects are assumed to be minimal but should also be investigated.
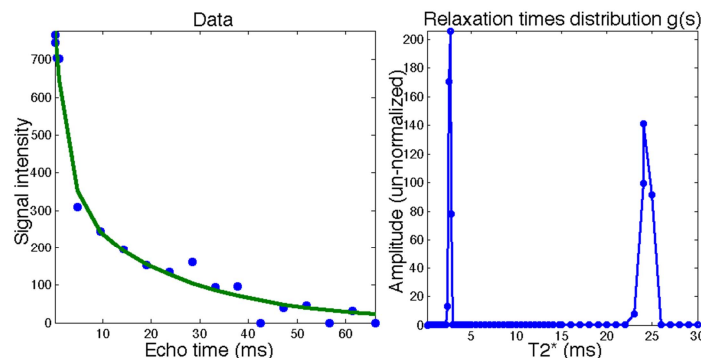

Figure 1: Plot of decay signal from a white matter region of interest (left) and resultant continuous distribution spectrum (right), showing a high amplitude short component of small line width and a long component of smaller amplitude and larger line width.
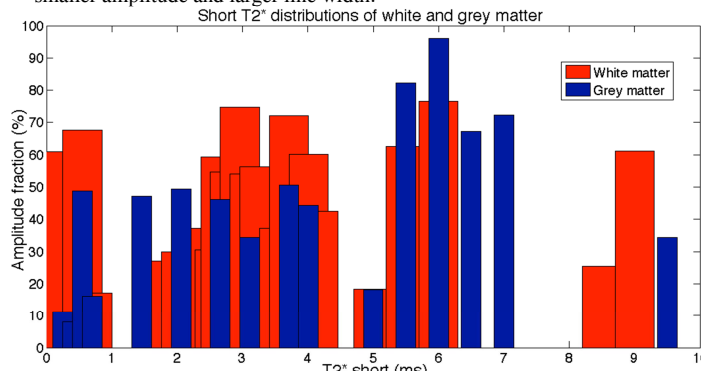

Figure 2: Bar plot of the estimated short T2* components against absolute amplitude fraction in the intervals of 0-10 ms. White matter samples in red, grey matter samples in blue.
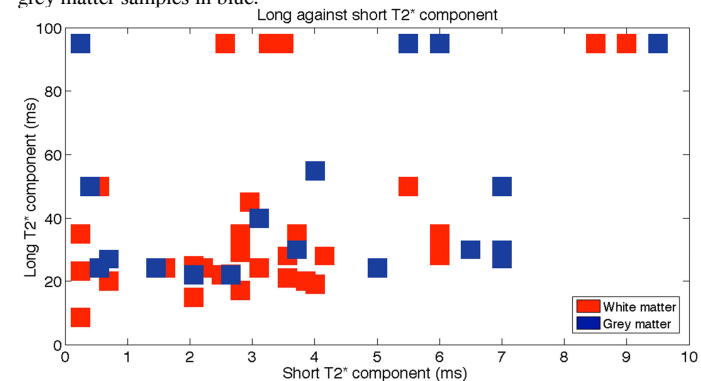

Figure 3: Scatter plot of the long T2* component against the short one. Results mainly fall in between 20-30 ms long T2* with short components between 0 and 10 ms.

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