Relaxometry using Transient Steady-State Free Precession Imaging

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Separation of tissue components by $T_2$ measurements is usually performed using multi-echo (CPMG) spin-echo or repeated single-echo sequences, followed by a multi-exponential fit in a voxel or region of interest. The minimum echo spacing limits the ability to measure short-$T_2$ components reliably. A new sequence that images during the transient period of an SSFP sequence can be used to obtain data with a slower exponential decay from short-$T_2$ components as well as two to three times the temporal sampling density. Results show that this technique can separate the short-$T_2$ component associated with myelin water in white matter.

Introduction: $T_2$-relaxometry is important for studying white matter diseases as well as tracking cartilage degeneration in osteoarthritis. $T_2$ measurements typically consist of acquisition of images at multiple echo times followed by a fitting technique such as the non-negative least squares (NNLS) algorithm [1]. Difficulties arise when fitting very short-$T_2$ species, such as myelin water because the minimum inter-echo spacing of about 10 ms or more limits the number of echoes with significant signal. The similarity between steady-state free precession (SSFP) imaging and multi-echo (CPMG) spin-echo sequences suggests that the transient period of SSFP can be used to acquire echoes with a much smaller inter-echo spacing than a CPMG sequence. Additionally, the slower signal decay from short-$T_2$ tissues means that more signal is available for the multi-exponential fit. Early results show that this method can quickly separate components based on relaxation time differences.

Theory: In a fully-refocused SSFP sequence, all gradients are rewound over a sequence repetition [2]. One of the characteristics of SSFP is the slow transient response toward the steady state. The seemingly complex transient magnetization can be described as an exponentially decaying system that rotates around the steady-state vector [3,4]. Moreover, if the initial magnetization is along the steady-state direction, the signal decay is purely exponential. The time constant, $\tau$, of this decay ranges from $T_1$ to $T_2$ as the flip angle varies from 0º to 180º, and is also slightly dependent on the resonant offset frequency.

Methods: Figure 1 shows the overall pulse sequence. Magnetization is first manipulated toward the steady-state direction in a prep stage [4,5]. Next, 256 repetitions of an SSFP sequence acquire the identical k-space line with TR=6 ms, TE=3 ms, and a flip angle of 60º. Acquisition is followed by a recovery period of 2 s with no pulses before the next overall repetition acquires the next imaging frame. Imaging was performed using a standard 256x192 Cartesian readout with 1x1.2 mm² resolution over a 24 cm FOV. A region-of-interest (ROI) was selected in an image series of a normal brain.

Results and Discussion: Figure 2 shows the ROI in the first image of the series, together with the exponentially-decaying signal and the fitted $\tau$-spectra. Based on the relaxation times in [6], the $\tau$ values in white matter would be 290±20 ms and 53±1 ms. This data indicates peaks at 270 ms and at 30 ms and myelin-water fraction of 27%. Although the $\tau$-values are reasonable, the myelin-water fraction is somewhat higher than the levels previously reported [6,7]. Further investigation of this difference will be necessary to validate this new technique for clinical use.

This technique is similar to that proposed by Scheffler and Hennig [8] to measure $T_1$ values. However, the improved prep stage allows the use of higher flip angles here, and no effort is made to measure $T_1$ or $T_2$ exactly. In the case of white matter, the expected time constants above allow good peak separation. The prep stage ensures that each species decays with a single exponential time constant, $\tau$; otherwise the decay usually has an additional oscillatory and exponential decay that will obscure measurement.

Conclusion: We have developed a new method for multi-compartment separation that uses the transient response of SSFP imaging. In some cases, this method will be helpful in fitting exponential curves by allowing mixing of $T_1$ and $T_2$. In all cases, the increased temporal sampling density will be helpful for additional averaging or reducing scan time.

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**Figure 1:** Transient SSFP imaging sequence. The prep phase manipulates magnetization to the steady-state direction. Image data are acquired during the exponential decay. After a 2 second recovery the process repeats.

**Figure 2:** Image showing region of interest (a), over which exponential decay (b) is fitted to determine the $\tau$-spectra (c).