Fast Spin Echo for T_2 Quantification at 3T

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INTRODUCTION

Due to rapid variation in the structural composition of human brain in early stages of life, T_1 and T_2 measurements offer a unique view into the details of brain maturation [1]. Such relaxation measurements featuring high resolution with whole brain coverage are characterized by long acquisition time and need for a steady subject during the long scan time. Difficulty of maintaining these conditions with infants has prevented the benefits of relaxation measurements to be fully explored in human brain development studies. In this work, we used a clinically available fast spin echo (FSE) sequence with high echo train length (HETL) of 32 to allow T_2 relaxation measurements within a short time tolerable for newborn children. The accuracy of our HETL-FSE has to be verified for T_2 quantification.

METHODS

A 2D multi-slice fast spin echo was implemented on a 3T GE Signa whole body scanner using an 8-channel phase-array head coil. To make the scan even faster, ASSET (parallel imaging) option was also used. The acquisition parameters for FSE were: slice thickness = 3.0 mm, FOV = 18cm, Phase FOV = 0.8, matrix size 256x128 zero-padded to 256x256, BW = 15.63 kHz, NEX = 1, ETL = 32 and TR = 3500 ms, $TE_{eff} \approx$ 39, 65, 105, 144, 170, 209, and 248 ms. With these parameters, 38 slices were obtained in 72 seconds for each TE. Seven newborn babies (aged from 2 to 12 days) have been scanned using these parameters. Before scanning the babies, we tested the accuracy of FSE with our chosen parameters on a phantom consisting of tubes of T_2 solutions (copper sulfate with different concentration). T_2 values obtained using FSE with and without ASSET were compared with those obtained using conventional spin-echo (SE) sequence.

RESULTS AND DISCUSSIONS

In FSE imaging, T_2-weighting in k-space causes the blurring or the edge enhancement in the phase-encoding direction [2]. Simulations showed that the T_2-weighting in k-space would considerably change the T_2 estimation for small objects and in the edge regions, which span a few pixels in the phase-encoding direction. Therefore, T_2 values for small objects or in the edge regions are subject to more scrutiny in T_2 maps. Higher image resolution may alleviate this problem at the price of longer scan time. We used a high echo train length (ETL=32) and small echo spacing (13 ms), which substantially reduced the scan time and made a relatively smooth weighting function, which caused less ringing artifacts due to the discontinuity in the weighting function. It is important to note that the zero-phase-encoding (ZPE) line is acquired after repeated refocusing in FSE.

T_2 values obtained by different sequences were calculated using a nonlinear least squares fitting (Table 1). Whether we chose linear ($S = S_0 e^{-TE/T_2}$) or nonlinear least squares fitting ($S = A + Be^{-TE/T_2}$, with *A, B* and T_2 positive) considerably changed the estimated T_2 values. In practice, nonlinear fitting gives more consistent results for SE when *A* is limited by the noise level of images. T_2 values obtained in phantom by different methods are plotted in Figure 1. If the noise level is considered and included as a constraint in nonlinear optimization, T_2 values obtained by FSE are consistent with the values obtained by SE. Considering the low image noise level, even linear fitting for FSE gives reasonably consistent T_2 values for the range of 150-350 ms, which covers the normal T_2 range in neonatal brains [1]. For other shorter or longer T_2, a new fitting equation ($S = A + Be^{-TE_{eff}/T_2} e^{-TE_{eff}/T^{*}}$) was used in constrained nonlinear fitting for FSE. This term $e^{-TE_{eff}/T^{*}}$ may account for additional signal loss due to repeatedly refocused ZPE line. Using this modified fitting scheme, T_2 can be more consistent between SE and FSE in a much larger T_2 range. Also in Table 1, effective T_2 of oil measured by FSE is much larger than the value measured by SE. This large discrepancy for oil-like materials can be explained by the J-coupling effects, which also explain the intensity increase of fat signal in FSE [3]. Water-like materials show more consistent T_2 values between FSE and SE.

Table 1. T_2 (ms) measured in phantoms. (* ASSET)

	Oil	Tube1	Tube4	Tube5	Tube6
SE	88	77.7	193.1	251.9	367.6
FSE	133	78.7	195.3	252.8	349.8
FSE*	124	75.6	199.0	262.6	374.3

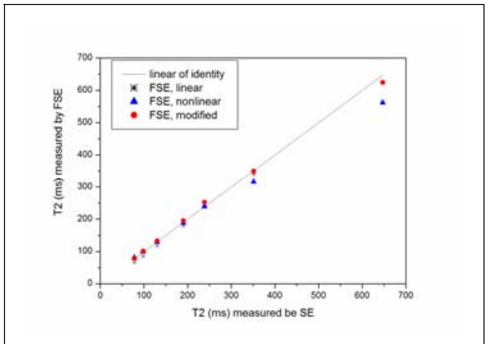

Figure 1. Linear fitting for FSE gives T_2 results consistent with the results for SE in the T_2 range of 150-350 ms. For nonlinear fitting, modification of the fitting equation for FSE could give more consistent T_2 values in a larger range.

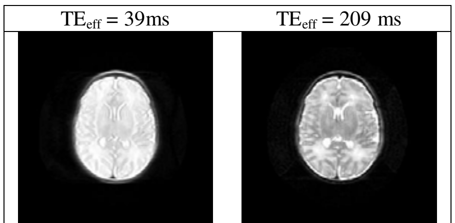

Figure 2. FSE images were acquired at different effective TEs using the acquisition parameters indicated in the text. Effective TE used in calculation of T_2 was decided by the time when the echo train crossed k=0.

Examples of T_2-weighted FSE images of infant brains are shown in Figure 2. T_2 maps of infant brains were obtained using linear (2-parameter) least squares fitting and nonlinear (4-parameter) fitting with constraints, respectively (Figure 3). For selected ROI in Figure 3, comparable T_2 results were obtained using linear fitting (WM: 263±7 ms; GM: 177±6 ms) and nonlinear fitting (WM: 266±8 ms; GM: 167±7 ms), though the former was much faster and the latter was assumed to be more accurate. T_2s for WM and GM of the infant brains are listed in Table 2.

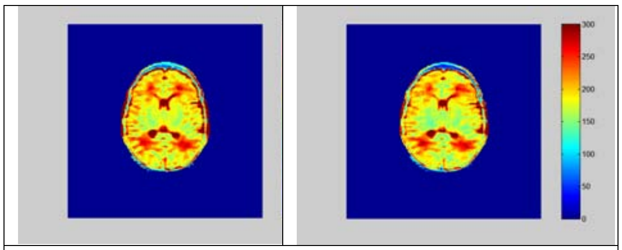

Figure 3. T_2 maps of infant brain obtained using: (left) linear least squares fitting; (right) modified nonlinear least squares fitting with constraints.

Table 2. T_2 for WM and GM of neonatal brains at 3T

	T_2(ms) of WM	T_2(ms) of GM
Linear fitting	298±32	184±14
Nonlinear fitting	306±47	176±11

CONCLUSION

T_2 Relaxation times were measured using high ETL fast spin echo in phantoms and infant brains with acceptable accuracy. The error in using FSE for T_2 measurement was determined by comparing their results with conventional SE measurements. A modified equation was tested to account for the differences between SE and FSE in T_2 estimation. This modified equation was shown to enable extraction of accurate T_2 values in phantom. An ASSET-compatible FSE with high ETL (32) is a necessary for such fast T_2 quantification in infant studies.

REFERENCES

[1] Williams, et al. Radiology 2005;235:595-603. [2] Constable, et al. MRM 1992;28:9-24. [3] Constable, et al. MRI 1992;10:497-511.