T2 Estimation Using A Half Fourier Radial Fast Spin-Echo Method

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Introduction: Evaluation of the T2 relaxation time holds great potential for diagnosis of pathological disorders. However, the generation of T2 maps is not practical in the clinical setting due to long acquisition times (~ 10 min or longer). Recently, it was demonstrated that high-resolution images at different effective TE (TE_{eff}) values can be generated from a single radial fast-spin echo (RAD-FSE) k-space data set using a simple algorithm[1,2]. In this method (referred to as the "multi-tier" method), images at various TE_{eff} are generated by including data acquired at a specific TE in the central part of k-space up to a radius determined by the Nyquist criteria. Beyond this first Nyquist radius, views acquired at other TE values are included gradually as illustrated in Fig. 1. The images at different TE_{eff} values are then used to estimate high-resolution T2 maps. With this methodology T2 maps can be obtained rapidly (e.g. a breath hold).

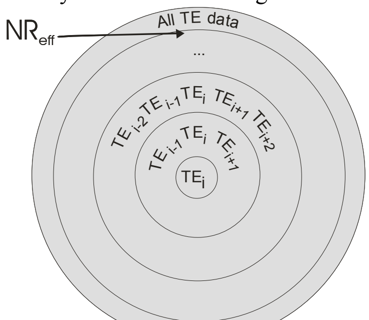

Fig. 1

Although it was demonstrated that the "multi-tier" method yields accurate results for large objects (> 8 pixels in diameter), there is bias in the T2 estimation for objects with high spatial frequency content such as small objects (less than 6 pixels in diameter) and edges[3]. It was shown that the error in T2 estimation is dependent on the effective Nyquist Radius (NR_{eff}) which is the radius after which all TE data are included (see Fig. 1). This is because beyond the NR_{eff} there is no signal intensity change due to T2 decay through the images at the various TE_{eff} values. This leads to an overestimation of T2 for small structures because these objects have significant energy at the high-spatial frequencies.

One way to reduce the T2 bias for structures with high-spatial frequency content is to increase the NR_{eff} by collecting more radial views. This approach, however, may not be feasible in many clinical applications, due to restrictions on imaging time (as in the case of breath hold acquisitions).

In this work, we use partial Fourier methods (developed previously to improve the time efficiency of 2D and 3D radial projection imaging[4-9]) to increase the NR_{eff}, and thus, improve the T2 estimates of small objects.

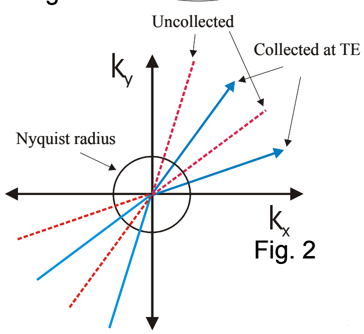

Fig. 2

Method: The basic principle of partial radial Fourier methods is to collect two radial half views in one readout period using a bent k-space trajectory[6-9]. The k-space trajectory for the bent RAD-FSE that is used in this work is illustrated in Fig. 2. The solid lines in the figure represent the acquired data, and the dashed lines represent the uncollected data. For the bent trajectory the readout gradients in RAD-FSE are modified such that the angle of the acquisition is changed at the origin of the k-space during the acquisition of each radial line. Thus, two half radial views are collected instead of a single full radial view. The uncollected half of each radial view is estimated using the single-TE interpolation method[8]. In this method, the uncollected k-space points that are within a Nyquist radius are calculated using linear interpolation in the angular direction. The interpolation is performed using views that are collected at a specific TE to avoid smearing due to different signal weighting between adjacent views. The missing k-space points that are outside of the Nyquist radius are calculated using homodyne detection in the projection domain[5]. Once the full radial views are generated, partial k-space data sets for each TE_{eff} value are created as illustrated in Fig. 1. Images at various TE_{eff} are then reconstructed using filtered backprojection. T2 maps are produced from these TE images by fitting the pixel intensities, I, to $I = I_o e^{\frac{-TEeff}{T2}}$. Note that since two full radial views are created from the two acquired half radial views, the Nyquist radius of each tier in Fig. 1 is doubled compared to a full view RAD-FSE acquisition. Thus, the NR_{eff} is also doubled allowing the T2-weighted contrast to be extended to higher spatial frequencies.

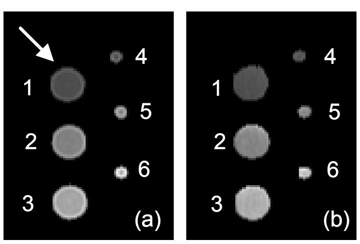

Fig. 3. T2 maps reconstructed from: (a) 256 full views, (b) 256 bent views.

Table 1: Comparison of T2 values obtained from different methods. %Δ indicates the % difference with respect to the gold standard.

	Gold Std.	256 Full Views		256 Bent Views	
Object	Mean T2	Mean T2	% Δ	Mean T2	% Δ
1	104.02	110.25	6	105.93	2
2	174.07	185.34	6	178.04	2
3	247.81	231.56	7	232.39	6
4	106.92	130.33	22	115.92	8
5	178.75	209.08	17	183.75	3
6	245.22	269.00	10	256.56	5

Results and Discussion: Experiments were conducted on a 1.5T MRI GE Signa scanner. A phantom containing three big (1 cm in inner diameter) and three small (0.5 cm in inner diameter) tubes with agarose concentrations of 0.4%, 0.6, and 1.2% was prepared. To evaluate the proposed method, data were acquire using the full-view and bent RAD-FSE pulse sequences. In both cases, the data were acquired with ETL=8, readout points=256, and receiver bandwidth = ±31.2 kHz. The echo spacing was set to 20 ms to cover TE's from 20 ms to 160 ms. The FOV was set to 20 cm to yield roughly a 12-pixel diameter object a 6-pixel diameter object for the 1 cm and 0.5 cm diameter tubes, respectively. The full view RAD-FSE sequence was first used to acquire 2048 views in order to generate regular TE images (i.e. without TE mixing) each having 256 views. These data were used to obtain a T2 map representing the "gold standard".

The full-view and bent RAD-FSE pulse sequences were then used to acquire data sets with 256 full views and 256 half views, respectively (i.e., 32 views per TE). These datasets were used to calculate T2 maps using the "multi-tier" method. The average T2s for each of the 6 tubes are tabulated in Table 1. The T2 maps are shown in Fig. 3. The results indicate that the T2 bias for small objects is significantly reduced with bent-RAD-FSE. Also, note that the edge artifacts in the full-view T2 maps illustrated by the arrow in Fig. 3 are significantly reduced in the bent T2 maps.

Conclusion: A method based on a bent k-space trajectory and half Fourier reconstruction was developed for obtaining high-resolution T2 maps from a single RAD-FSE k-space data set. With this method the effective Nyquist radius (NR_{eff}) is doubled compared to the conventional radial k-space trajectory where a full k-space line is acquired per readout period without increasing imaging time. This significantly reduces the T2 bias for small objects. The proposed method may lead to accurate diagnosis of pathologies in small lesions. Further improvements can be achieved using parallel imaging techniques or iterative T2 estimation methods.

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References: [1] Song HK, MRM, 44, 825 (2000). [2] Altbach MI, JMRI, 16, 179 (2002). [3] Altbach MI, MRM, 54, 549 (2005). [4] Noll DC, IEEE TMI, 10, 154 (1991). [5] Noll DC, Proc. SPIE, 1443, 29 (1991). [6] Block WF, Proc. ISMRM, (1999). [7] Toropov, Proc. ISMRM (2001). [8] Bilgin A, Proc. ISMRM, (2004). [9] Bilgin A, Proc. ISMRM, (2005).