Further exploration of MRI techniques for liver T1rho quantification

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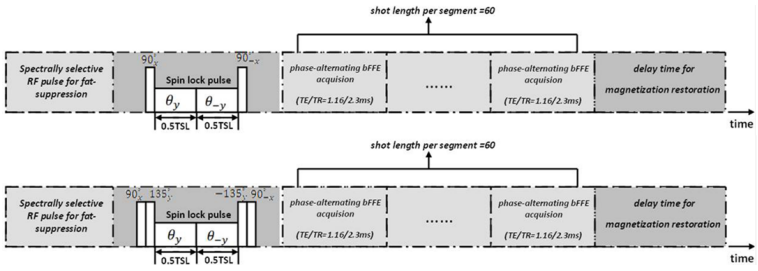
Introduction: With biliary duct ligation and CCl4 induced rat liver fibrosis models, recent studies showed that MR T1rho imaging is able to detect liver fibrosis, and the degree of fibrosis is correlated with the degree of elevation of the T1rho measurements, suggesting liver T1rho quantification may play an important role for liver fibrosis early detection and grading [1,2]. We reported it is feasible to obtain consistent liver T1rho measurement for human subjects at 3 T [3]. In a healthy volunteers study, three representative axial slices were selected to cut through the upper, middle and lower liver. Regions of interest (ROI) were manually placed on each slice of the liver parenchyma region, excluding artifacts and vessels [3,4]. Using both theoretical simulation and practical validation, we reported it is possible to accelerate T1rho relaxation quantification in liver by using limited spin-lock time points [4,5]. Preliminary clinical data suggest liver T1rho is increased in patients with cirrhosis [6]. In these previous studies [1-6], T1rho imaging was used with the rotary-echo spin-lock pulse (Fig.1) for T1rho preparation, and NSA was 2. Due to the presence of inhomogeneous B_0 field, artifacts may occur in the acquired T1rho-weighted images. The method described by Dixon et al. [7], which is a hard RF pulse with 135° flip angle and same RF phase as the spin-locking RF pulse is inserted right before and after the spin-locking RF pulse, has been proposed to reduce sensitivity to B_0 field inhomogeneity in T1rho imaging [7,8]. In this study, we compared the images scanned by rotary-echo spin-lock pulse method (Fig.1, sequence 1) and the pulse modified according to Dixon method (Fig.2, sequence 2). The delay time for magnetization restoration was 6000ms. When NSA = 2, the breath-holding duration for data acquisition of one slice scanning was 8 sec. If the NSA = 1, the duration was 2 sec. In our previous studies, manual ROI analysis of T1rho map was used. In this current study, histogram analysis was also applied to evaluate liver T1rho value on T1rho maps. The purpose of this current study was three fold: 1) to compare method 1 and method 2 to see whether method 2 would reduce artifacts; (2) to evaluate whether the images with NSA=1 had sufficient SNR; (3) to compare the results of manual ROI analysis and histogram analysis.

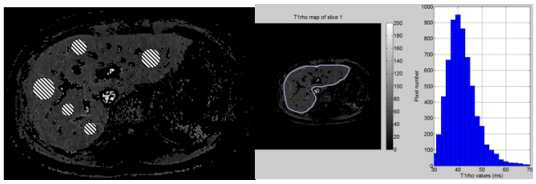
Material and Methods: MRI data acquisition was performed on a 3T clinical scanner (Achieva, Philips Healthcare). An 8 channel cardiac coil was used as the signal receiver to cover the liver, and the in-built body coil was used as the signal transmitter. Subjects were examined supine. Liver anatomical imaging covering the whole liver was carried out using a standard axial breath hold T2-weighted SPAIR (Spectral Adiabatic Inversion Recovery) sequence. Using axial T2-weighted image as reference, representative axial slices were selected to cut through the liver for T1 rho imaging. The T1rho preparation pulse was implemented in a single shot 2D fast field echo (FFE) sequence with centric phase-encoding acquisition for T1rho measurement (sequence 1: Fig.1, sequence 2: Fig.2). Spin-lock frequency was set as 500 Hz and the spin-lock times of 1ms, 20 ms, and 50 ms were used for T1rho mapping [5]. TE and TR for FFE acquisition were 1.16 ms and 2.3 ms respectively. The voxel size was 1.50×1.50×7.00 mm3. The flip angle was 40 degrees. 29 healthy volunteers were included in this analysis, the subjects of T1rho MR imaging with different protocols were listed in the table 1. 17 subjects with 34 scans scanned with method 1 and NSA=2 was reported in our previous studies [3, 5]. The additional 12 subjects were added in this study, they all were scanned with method 2 and NSA=2, 6 subjects were examined additionally with method 1, and 9 subjects were also scanned with NSA=1. When the artifacts occurred in T1rho images, we repeated the same scan until satisfactory images were obtained. We accepted images if artifact in liver was less than 10% of liver area by visual estimation. In previous measurement, we quantified the T1rho values by setting 5 ROIs of 100-200mm^2 on liver parenchyma region of each slice's T1rho maps, with R^2>0.80, excluding the observable artifacts and blood vessels (Fig. 3). In histogram analysis, the whole liver parenchyma was included with R^2>0.80, the numbers of each T1rho value range in whole liver were presented as Fig.3. The T1rho value range for the highest peak was recorded and compared with the T1rho values measured by ROIs method. For example, in Fig.3, the T1rho values in 5 ROIs were 42.5, 41.5, 39.5, 41.1, and 38.9 ms, leading to a mean value of 40.7 ms. Meanwhile, in the histogram of Fig. 3, the T1rho values range for the highest peak in the histogram was 40-41 ms, leading to a value of 40.5 ms with the histogram method.

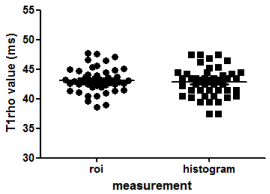


Scanning protocol	Subject number: Volunteers reported*	Subject number: New volunteers**	Scan number: Volunteers reported*	Scan number: New volunteers**	Measurement method: ROI	Measurement method: histogram
Sequence 1, NSA=2	n=17	n=6	n=34	n=6	n=40	n=40
Sequence 2, NSA=2	n=0	n=12	n=0	n=12	n=12	n=12
Sequence 1 & 2, NSA=2	n=0	n=6	n=0	n=6		
Sequence 2, NSA=2 & =1	n=0	n=9	n=0	n=9		

Fig.1 Diagram of the spin-lock fast field echo (FFE) imaging sequence for T1rho image. TSL= time of spin-lock pulse. The rotary-echo spin-lock pulse method was used for T1rho preparation. ***Fig.2*** *Diagram of the spin-lock fast field echo (FFE) imaging sequence for T1rho image. TSL= time of spin-lock pulse. The rotary-echo spin-lock pulse was modified with Dixon method was used for T1rho preparation.* ***Table 1.*** *Subject number of T1rho MR imaging with different scanning protocols. *: Volunteers already reported in reference 3 and 5. **: additional volunteers recruited for this study.* ***Table.2.*** *percentage of satisfactory images per acquisition using Sequence 1 or Sequence 2.* ***Fig.3*** *T1rho measurement methods (ROIs method (left), histogram method (right)) in a subject.* ***Fig.4*** *T1rho values measured by ROI method and histogram method in all subjects with NSA=2 (n=52).*

scanning protocol	percentage of satisfactory images per acquisition: SL01	SL20	SL50
Sequence 1	70.0%	55.8%	59.0%
Sequence 2	60.5%	51.1%	56.1%





Results: Liver T1rho values obtained by sequence 1 (NSA=2) and sequence 2 (NSA=2) showed similar values, i.e. 43.1±2.1 ms (range: 38.6-48.0 ms, n= 40 scans) vs 43.5±2.5 ms (range: 39.0-47.7 ms, n= 12 scans, p=0.7445) respectively. For the 6 volunteers scanned with both sequences in one session, the ICC was 0.939 (by ROI measurement). The Bland and Altman analysis showed a mean difference of 0.3 (95% limits of agreement: -1.51, 2.11). The percentage of images without obvious artifacts (less than 10% of liver area) for sequence 1 and sequence 2 in each slice was listed in Table 2. Overall, the success rate of obtaining satisfactory images per acquisition was slightly over 50%. Satisfactory images can usually be obtained by asking the volunteer subjects to better hold their breath. Sequence 2 did not increase the scanning success rate. For the 9 subjects scanned by sequence 2 with both NSA=2 and NSA=1 during one session, the ICC was 0.274. The Bland and Altman analysis showed a mean difference of 5.01 (95% limits of agreement: -7.20, 17.22). The T1rho values measured by ROI method and histogram method was showed in Fig.4. These two methods for T1rho measurement in all examinations (sequence 1 & 2, NSA=2, n=52 scans) had an ICC of 0.901. The Bland and Altman analysis showed a mean difference of 0.32 (95% limits of agreement: -1.59, 2.24).

Discussion: Our results suggested by including 135° flip angle before and after the spin-locking RF pulse, the rate of artifacts occurring did not decrease. On the other hand, sequence 1 and sequence 2 measured similar T1rho value in healthy liver. While reducing the breath–holding duration significantly, NSA=1 did not offer satisfactory SNA and the measured T1rho values had a very poor agreement compared with results from NSA= 2. The histogram measurement and manual ROI measurement provided similar liver T1rho value. Previously, we reported healthy liver T1ho measurement in 17 subjects, and additional 12 subjects are reported in this study. Pool all the results together (n=52), our data showed a mean liver T1rho value of 43.2±2.2 ms, with a range of 38.6- 48.0 ms.

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