Stimulated Echo Diffusion Weighted Imaging of the Liver at 3T

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TARGET AUDIENCE: Researchers and clinicians interested in stimulated echo DWI in the liver imaging

PURPOSE: Diffusion-weighted imaging (DWI) has been increasingly used in clinical applications due to its sensitivity to microscopic motion from either the water molecular Brownian motion or the blood microcirculation in biologic tissue [1]. However, the DW signal depends on not only b-value but also the diffusion time (Δ) [2] because water molecule diffusion is hindered and restricted by cellular microstructures, such as cell membrane, cytoskeleton and macromolecules in tissue environment [3]. The study of restricted diffusion in human liver has been rarely reported so far due to lots of challenges (such as fat suppression, motion control) although one study was done in rat livers [4]. This work proposed an optimized stimulated-echo (STE) DWI method at 3T and aimed to investigate the dependence of diffusion measurement on Δ in healthy human liver.

METHODS:

Sequence optimization: All MRI experiments were performed on a Philips 3T clinical scanner (Philips, Best, The Netherlands). The liver images were acquired from 5 healthy volunteers by using a 32-channel SENSE Torso/Cardiac coil with a respiratory triggered single-shot STE EPI DWI sequence. The optimizations include: a) *Fat suppression*: We incorporated a new fat suppression technique, Slice-Selective Gradient Reversal (SSGR) [5] into the STE DWI sequence. b) *Eddy currents compensation*: To minimize the eddy currents, we introduced two extra gradients between the 2nd and 3rd RF pulse as a new eddy current compensation method [6]. c) *Respiratory motion control*: By using respiratory trigger instead of breath-hold, we have enough time to apply much more b-values for curve fitting. d) *Data rejection*: Additionally, before data analysis, we also rejected the motion corrupted data with severe signal voids on the liver parenchyma upon visual inspections from the repeated scans. Then the rest qualified data were averaged for analysis. This helps to further compensate the respiratory and cardiac motions. By this mean, the accuracy of apparent diffusion coefficient (ADC) calculation can be improved for tissue characterization.

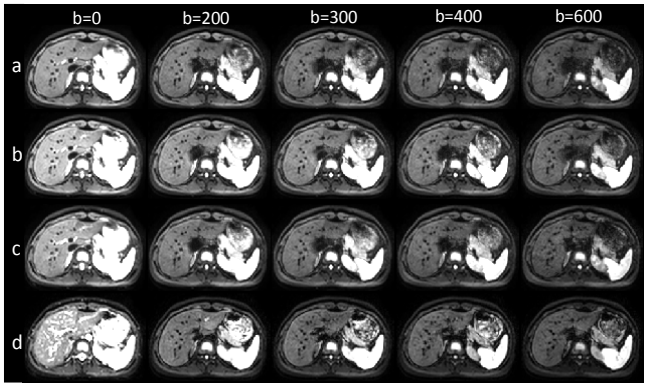

Fig. 1 Representative SE and STE EPI DWI with 5 b-values. From top to bottom, the images are: △=80ms (a),106ms(b),180ms(c) and SE (d) (△=32ms) respectively.

Data acquisition: All liver DWI data with 5 b-values were acquired covering 3 central slices of the liver with slice gap=9mm. Other parameters are shown as follows: FOV=300×210 mm^2, acquisition matrix=92×60, slice thickness=5mm, σ =8ms, TR/TE=1600/53ms, SENSE =2, trigger delay=500ms, scan time ≈130s, b values=0, 200, 300, 400, 600 s/mm^2. Different diffusion time Δ= 80,106,186ms were used. The shortest Δ actually was depended on the maximum gradients strength of the scanner when the gradient duration was fixed. 9 times were repeated for STE DWI and 3 times for SE-DWI respectively. All subjects provided written informed consent. A single-shot spin echo EPI DWI with one single diffusion time (the equivalent diffusion time =32ms) was also acquired as a reference.

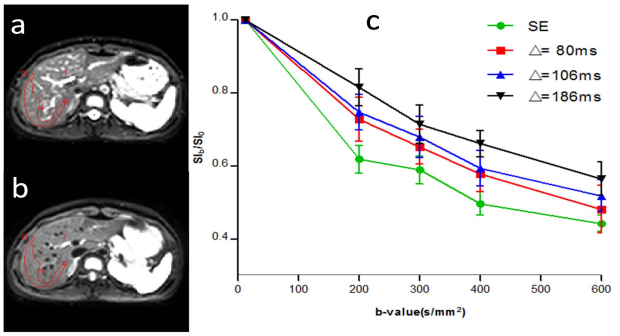

Fig. 2 Mean DWI signals, computed as the average of all DWI signals measured from 5 volunteers at different △. a) SE-DWI B0 image; b) STE-DWI B0 image, c) normalized signals for SE and STE DWI.

Data analysis: ROIs excluding large blood vessels were drawn on the liver parenchyma. Then ADC was obtained by fitting the equation: $SI_b/SI_0 = \exp(-b \times ADC)$ from the ROI measurements using a least square nonlinear fitting algorithm in Matlab (The Mathworks Inc., Natick, MA).

RESULTS: Representative SE DWI and STE DWI images of the liver from one volunteer with five b-values at three diffusion times are shown in Fig. 1. Fig. 2c shows the mean liver DWI signals from the ROIs in Fig 2a and b. They were computed by averaging the normalized DWI signals (SI_b/SI_0) from all volunteers. Error bars indicate the standard deviation among these subjects. When the diffusion time increases, the signal decay becomes slower. Fig. 3 shows the comparison of the liver ADCs among three diffusion times, which confirms the statistically significant dependency on diffusion time for the ADCs of liver tissues.

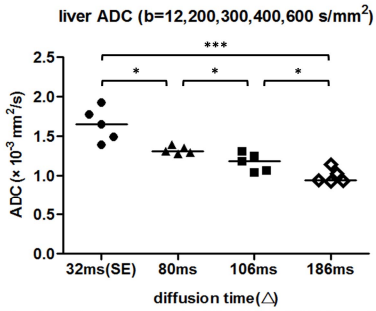

Fig. 3 ROI measurement of the liver ADC from SE DWI and STE DWI. Paired T-test was performed with * for P<0.05,** for P<0.01,*** for P<0.001.

DISCUSSIONS AND CONCLUSIONS: Based on the diffusion theory, the decrease of ADC with increasing Δ is expected since the diffusion of water molecules will change from random into restricted motion when encountering barriers with a long enough Δ. According to the results from the rat liver model, the diffusion distance of water molecules probed by Δ= 186ms will be comparable to the average cell size of hepatocyte in the normal liver [8]. The results in this study show that restricted diffusion behavior is observed in human liver in vivo at 3T, which demonstrates the effect of both b-value and Δ on liver diffusion quantification. Thus diffusion time might be a sensitive biomarker to detect the pathological alterations in tissue microstructure during human liver firbrogenesis. Further clinical validation studies will be conducted on liver fibrotic patients.

REFERENCES:

[1] Lebihan D, et al. Radiology 1988; 168(2):497. [2] Horsfield MA, et al. MRM 1994; 31(6): 637. [3] Cooper RL, et al. Biophysical Journal 1974; 14(3):161. [4] Iris Y. Zhou.et al. MRM. 2014; 72(5):1389. [5] Park HW, et al. MRM. 1987; 4(6):526. [6] T.G Reese, et al. MRM .2003; 49(1):177. [7] Cheung JS, et al. Acad Radiol 2011; 18:377.