Reduction of cardiac motion-related effects on liver diffusion imaging

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Target Audience: Researchers and clinicians interested in liver diffusion imaging.

Purpose: Diffusion MRI of the liver is affected by cardiac motion. This leads to signal voids in diffusion-weighted images (particularly in the left liver lobe, located directly inferior to the heart) and results in errors and high variability in ADC measurements[1-5]. This variability has precluded the widespread application of quantitative liver diffusion MRI, and also impacted the reliability of qualitative liver DWI for detection of focal liver lesions. The ***purpose of this work*** was to characterize cardiac motion effects on liver diffusion imaging (*experiment 1*), and to assess correction techniques to reduce cardiac motion effects on ADC (*experiment 2*).

Methods: Healthy volunteers were scanned at 1.5T (GE HDxt, GE Healthcare) in accordance with the local institutional review board.

Experiment 1: single-slice axial DW-EPI was acquired in a single breath-hold (BH) on three volunteers, covering the right and left liver lobes. Parameters included: 6mm slices, FOV=38×38cm^2, acquisition matrix=192×144, TE=78ms, parallel imaging R=2, cardiac-triggered (peripheral gating) with TR=2RR intervals, b=0, 200, 400, 500, 600, 700 s/mm^2. To assess the artifacts in DW images at different phases of the cardiac cycle, the acquisition was repeated with different cardiac trigger delays (TD=100, 200, 300, 400ms). ADC maps (excluding the b=0 image) were reconstructed in two ways: a) by averaging the signal over all TDs, prior to ADC estimation or b) by maximum-intensity projection (MIP) over all TDs, prior to ADC estimation[3,5].

Experiment 2: Whole-livers of five healthy volunteers were scanned using respiratory-triggered (RT) and BH protocols, with b values = 0, 200, 800 s/mm^2. Each acquisition had 4 signal averages (BH: acquired in separate breath-holds). No cardiac triggering was used in order to test the effects of randomly distributed acquisitions over the cardiac cycle. To test repeatability, RT and BH scans were repeated after having the volunteer adjust their position inside the scanner bore, and re-localizing, for a total of four acquisitions (two RT and two BH). ADC maps were reconstructed using three methods: a) averaging the four signals at each b-value, b) MIP over the four signals at each voxel, c) "hybrid" approach, where signals > 50% of the maximum intensity were averaged, and signals < 50% were discarded at each voxel (in order to avoid signal voids but maintain better noise properties compared to ADC_{MIP}).

One blinded radiologist placed regions-of-interest in the left and right lobe on three adjacent slices in the ADC maps for each of the four acquisitions, co-localized across all three reconstruction methods. Variability in ADC was assessed by calculating the absolute difference between ADC in the right and left liver lobes, as well as in the same lobe between repeated acquisitions. Absolute differences of ADC_{MIP} and ADC_{Hybrid} were compared with $ADC_{Average}$ by using Wilcoxon's test.

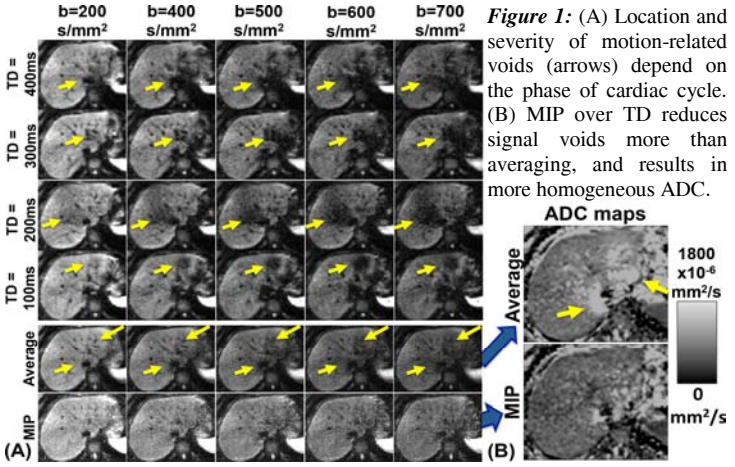

Figure 1: (A) Location and severity of motion-related voids (arrows) depend on the phase of cardiac cycle. (B) MIP over TD reduces signal voids more than averaging, and results in more homogeneous ADC.

Median absolute difference (range); (units: 10^{-6}mm^2/s)

		$ADC_{Average}$	ADC_{MIP}	ADC_{Hybrid}
Between right and left lobes				
	Breath-hold	**305** (2–865)	**85** (14–311)	**115** (11–344)
	p value Control		0.003	0.008
	Respiratory-triggered	**411** (19–1158)	**205** (12–777)	**129** (29–446)
	p value Control		0.034	0.008
Between repeated scans				
Right lobe	Breath-hold	**125** (12–653)	**60** (9–310)	**80** (18–283)
	p value Control		0.043	0.058
	Respiratory-triggered	**98** (12–689)	**74** (16–676)	**43** (0–448)
	p value Control		0.147	0.012
Left lobe	Breath-hold	**446** (8–1790)	**169** (0–1289)	**222** (1–1289)
	p value Control		0.138	0.277
	Respiratory-triggered	**271** (110–866)	**105** (6–502)	**113** (3–593)
	p value Control		0.004	0.008

Table 1: Variability in ADC measurements, determined by the median absolute difference (range) between right and left liver lobes, as well as between repeated acquisitions. Both MIP and hybrid methods for ADC mapping result in lower variability than averaging.

Results and Discussion: *Experiment 1:* Figure 1 highlights the variable location of signal voids over the cardiac cycle on representative DW images (Fig 1A) and ADC maps (Fig 1B). In this volunteer, no single choice of TD provided DW images free of signal voids. Averaging over the four TDs resulted in artifactually elevated ADC in regions of signal voids, whereas MIP over TDs provided more homogeneous ADC maps (at the cost of higher sensitivity to noise floor). Hence, scanning at different phases in the cardiac cycle may be needed in order to avoid regionally persistent signal voids.

Experiment 2: As shown in Table 1, $ADC_{Average}$ had high variability between right and left liver lobes (expected to have similar values in healthy volunteers), as well as between repeated scans. ADC_{MIP} and ADC_{Hybrid} had significantly decreased variability, particularly in the left lobe, for both RT and BH scans. Figure 2 shows ADC measurements from all five subjects, demonstrating the potential of ADC_{MIP} and ADC_{Hybrid} to address cardiac motion induced signal voids in the left lobe. ADC_{Hybrid} may outperform ADC_{MIP} in regions without motion induced signal voids, but further experiments are needed to test this.

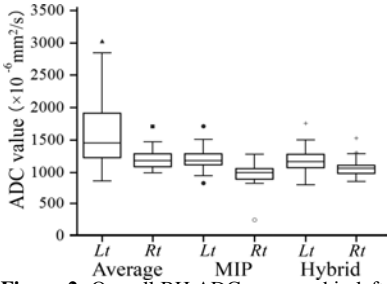

Figure 2: Overall BH ADC measured in left and right lobes. RT results were similar.

Conclusion: MIP and hybrid techniques decrease variability caused by cardiac motion in liver ADC maps.

References: [1]Schmid-Tannwald, Acad Radiol 2013; 20:440–445. [2]Murphy, MRM 2013;70:1460-1469. [3]Liau, JMRI 2013, 35(2): 318–327. [4]Ozaki, JMRI 2013;37:172–178. [5]Pai, MRM 2011, 65: 1611–1619.

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